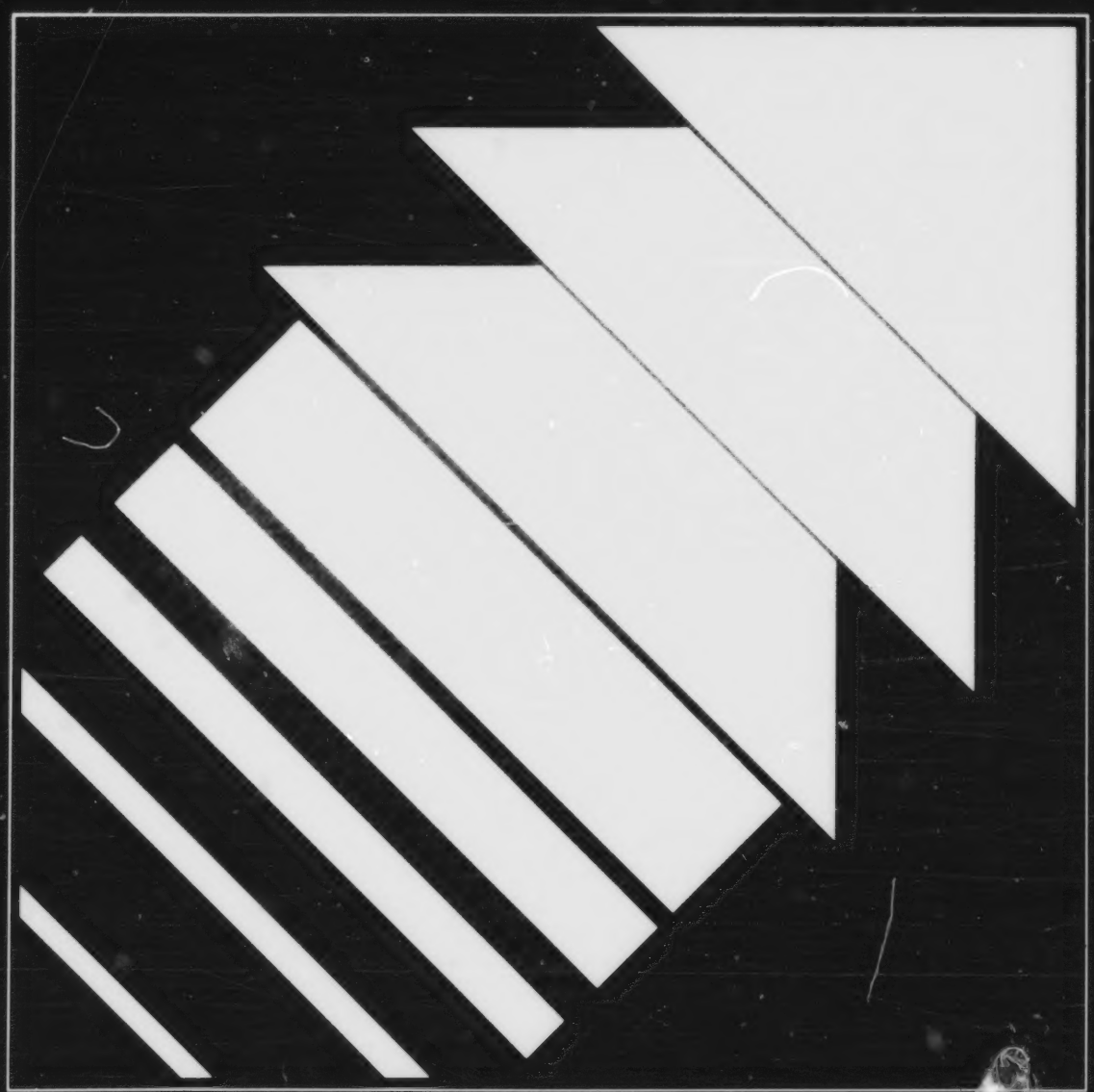
NATIONAL URANIUM TAILINGS PROGRAM



Energy, Mines and Resources Canada
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A Study of the Distribution of Naturally Occurring Radionuclides in Freshwater Benthos and Their Environment Phase II Report Field Program

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ABSTRACT

Sediments and invertebrates can be part of aquatic food chains leading to humans. Accurate estimation of radiation dose to humans through consumption of fish or other aquatic biota requires a good understanding of the pathways along which radionuclides move. There is a great lack of data on radionuclide levels in the "lower links" of aquatic food chains. Therefore, the principal objective of this study was to investigate the movement of radium-226 (Ra-226) and uranium (U) to aquatic sediments and invertebrates in areas affected by uranium mining and milling.

The study was conducted in two uranium mining areas, Elliot Lake, Ontario and Wollaston Lake, Saskatchewan. Samples of water, sediments and invertebrates were collected at five major sites in each area. Fish were also collected for data on fish food habits and for possible radionuclide analysis. Samples were analysed for Ra-226 and U. Distribution coefficients (K_d) for water to sediment, and bioaccumulation factors (BF) for water to invertebrates and sediment to invertebrates were calculated.

Sample variation and the ranges of K_d's and BF's were specified. Relationships between Ra-226 and U levels, K_d's and BF's and environmental parameters such as sample site or water quality were investigated using analysis of variance and principal components analysis.

Results showed that both Ra-226 and U K_d's and BF's were normally distributed, with small sample variation within specific sample sites. The K_d's and BF's were within the range reported in the literature; however, overall variation among sites and studies was so great that no "general" K_d or BF can be recommended for use in radionuclide pathway models.

Statistical analysis showed that U and Ra-226 levels in water, sediments and invertebrates were related to sample site. In addition, sediment U and Ra-226 levels were related to organic, iron and manganese content, and invertebrate U and Ra-226 levels were related to feeding group. Uranium and Ra-226 K_d's however, were not significantly related to any of the parameters tested.

Sediment-based BF's were very low compared to water-based BF's.

Uranium and Ra-226 BF's were related to sample site. This may be partially due to the effects of total dissolved solids and alkalinity on the solubility and uptake dynamics of the radionuclides.

Sediment-based U BF's and water-based Ra-226 BF's were significantly different among invertebrate feeding groups. Feeding groups at the bottom of benthic food chains did not necessarily have the highest BF's.

Analyses of fish stomach contents showed that Ra-226 and U levels were often higher and the mixture of fish food items different than in the invertebrate samples. Therefore, measurement of fish stomach contents may yield more accurate data for use in estimating dose to humans from consumption of fish. However, for the purposes of understanding radionuclide movement in ecosystems, studies of K_d's and invertebrate BF's are very useful and should be continued and expanded.

Results showed that accurate, credible use of K_d's and BF's demands site- and circumstance-specific data.

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1.0 INTRODUCTION

1.1 Rationale

The accurate estimation of doses received by humans from exposure to uranium and thorium series radionuclides released during uranium mining and milling depends upon a good understanding of the pathways along which these radionuclides move. All Canadian uranium mines are located either immediately adjacent to or very near lakes and streams. Therefore, one potentially major pathway for radionuclide movement near Canadian mines is the aquatic food chain, eg. water-invertebrates-fish-man. Most methods used to estimate dose to humans via aquatic food chains employ bioaccumulation factors for water to fish to derive radionuclide levels in fish. Then, either assumed or known human fish consumption data are used to estimate human radionuclide intake and dose. The problem with this approach is that the primary movement of radionuclides to fish and then to humans may not be from water; sediments may be an important source. In addition, the intervening steps in the food chain to fish (invertebrates) may greatly affect the rate and amount of radionuclide movement to fish. Therefore, in order to investigate whether or not present models of food chain transfer to humans are generating reasonable estimates, data on sediment and invertebrate radionuclide levels and transfer are required.

A review of available information on uranium and thorium-series radionuclide transfer from water to sediment, and water or sediment to invertebrates revealed that data are scarce, non-uniform in terms of sampling, preparation and analytical techniques and poorly documented (SENES and SRC 1984). Completely different types of invertebrates are frequently lumped together, replicates are rare and supporting data on water and sediment quality and habitat type are usually unavailable.

Our general objective was to study radionuclide levels in sediments and in invertebrates using standard uniform techniques, replication, more detailed invertebrate identification and supplementary or supporting data on environmental characteristics.

1.2 Objectives

The specific objectives of this project were to:

1. measure radionuclide levels in water, sediments and biota at selected sites near uranium mines in Ontario and Saskatchewan;

2. compute distribution coefficients (K_d) for water-sediment radionuclide transfer and bioaccumulation factors (BF) for water/sediment-invertebrate transfer for all sites sampled;

3. show sample variation and ranges for all K_d's and BF's;

4. statistically analyse the data for relationships between radionuclide levels, K_d's, BF's and environmental parameters; and

5. evaluate the applicability of K_d's and BF's derived in this study and make recommendations regarding their use.

1.3 Program Design Criteria

Study sites were chosen on the basis of: existing water quality and sediment data; invertebrate population and taxonomic data; other supporting hydrological, geological and geochemical data; the presence of food chains leading to man; applicability of the

study areas to other uranium mine sites; and, accessibility. Two areas, Wollaston Lake in Saskatchewan and Elliot Lake in Ontario, were chosen using these criteria.

The choice of radionuclides was based on environmental mobility, radiotoxicity, chemical toxicity, existing data bases for comparison and analysis cost. Uranium (U) and radium-226 (Ra-226) were selected. Uranium is the most mobile nongaseous element of the uranium or thorium series. It has relatively low radiotoxicity but is a potentially significant chemical toxin. It has the largest data base for water, sediment and biota. Uranium analyses are relatively inexpensive. Radium-226 is not as mobile as uranium but it is more mobile than, for example, thorium or lead-210. It is significantly radiotoxic and a relatively large Ra-226 data base exists (SENES and SRC 1984).

Selection of general groups of invertebrates for study was done prior to sampling using existing information from the chosen study areas. Once in the field, final selection of genera was done according to whether the organism was: known to be a fish food item, numerous, easily identified, and available for collection in large quantities using standard techniques.

The sampling program was devised to include: (1) standard sampling and sample preparation techniques; (2) replication at each sample location; (3) contemporaneous collection of support data on water and sediment quality; (4) forage fish and large fish collection for identification of stomach contents; and (5) radiochemical analysis of selected specimens. Data gathered using these criteria could then be analysed for sample variation, statistical difference with region, site, genus, and environmental parameters (water quality, sediment quality, habitat) and relationships between environmental parameters and relative radionuclide accumulation. The results of these

statistical analyses could then be used to assess the applicability of distribution coefficients and bioaccumulation factors derived from this study.

2.0 DESCRIPTION OF STUDY AREAS

2.1 Elliot Lake Area

2.1.1 Hydrology and Limnology

The Elliot Lake mining area lies within the Serpent River drainage basin, a 1376 km^2 area in the Algoma district of Ontario on the north shore of Lake Huron (Figure 2.1). A large proportion of the basin is occupied by natural lakes. The main drainage basin extends from the source above Ten Mile Lake (not shown on Figure 2.1) through Dunlop, Quirke, Whiskey, Pecors and McCarthy Lakes and then on to Lake Huron. A westerly sub-basin formed by Elliot, Esten, Nordic, Marshland and Depot Lakes joins the main drainage channel near the inlet to McCarthy Lake.

Mean annual flows in the Serpent River have been calculated as 21.2 m^3/s at the "Highway 17" gauging station and 2.9 m^3/s above Quirke Lake (MacLaren 1977). The long-term peak runoff is 2.66 times the mean annual flow; the long-term minimum flow is 0.40 times the mean flow (MacLaren 1977). Peak flows occur during spring runoff and in late autumn when rain runs off partly frozen ground. Minimum flows occur in mid-summer when evaporation and transpiration are high and in winter when precipitation is in the form of snow. Variations in flow in the Serpent system are not large as the lakes have a moderating influence on short-term fluctuations in flow and the effects of these fluctuations on water quality (MacLaren 1977).

The lakes in the Serpent River drainage are glacial scour basins; therefore, they are larger than would be expected from the size of the river. The lakes in the upper part of the basin are typical of the oligotrophic lakes of the Precambrian Shield. They are deep, cold, low in fertility and high in dissolved

oxygen (OWRC 1972). In the lower part of the basin, the lakes are more productive. They have greater fertility and are shallower (OWRC 1972).

Detailed physical and chemical data from many of the lakes are scarce or non-existent. Morphological data from three of the lakes sampled in this study were available (Table 2.1). Temperature measurements in thirteen lakes in the area (including three sampled in this study) revealed that all stratified during the summer (MacLaren 1977).

2.1.2 Uranium Mines in the Drainage Basin

Operating Mines

All present mining activity is located downstream of Dunlop Lake. The first source of mine effluent to the Serpent River enters at Stollery Lake (Figure 2.1). Runoff from the Long Lake tailings area operated by Denison Mines is treated with barium chloride and discharged to Stollery Lake. A dam across the middle of Stollery Lake contains and provides a settling area for the barium-radium precipitate (OWRC 1972).

A second tailings effluent is discharged to the Serpent River just downstream of Stollery Lake. This effluent originates from the Quirke mine operation of Rio Algom Limited. Seepage and tailings decant from the Quirke tailings management area are treated with barium chloride and the precipitate is allowed to settle in a series of ponds before the effluent is released to the Serpent River.

A third source of tailings effluent is from Rio Algom's Panel mine located on the north shore of Quirke Lake. The Panel operation effluent is treated with barium chloride and allowed

to settle in modern, lined settling ponds before discharge directly to Quirke Lake.

The fourth active uranium property is Rio Algom's Stanleigh mine which is located on the lower limb of the Elliot Lake ore body. The Stanleigh mine has a barium chloride and lime treatment plant to treat effluent from Crotch Lake. Treated effluent is filtered before entering the main branch of the Serpent River via the McCabe-May-Hough-Pecors Lake chain.

Non-operating Mines

Rio Algom's Nordic mine operated until 1970 (OWRC 1972). Wastes were directed to a disposal area north of the mill (Figure 2.1). This area also receives runoff from the Lacnor tailings area, which is located about 1.5 km north of the Nordic mine. Runoff from the Nordic tailings area is treated with lime and barium chloride for pH adjustment and Ra-226 removal. The chemically treated effluent is passed through a settling pond to remove the metals and Ra-226 precipitate. The treated effluent then flows along Buckles Creek into Nordic Lake which drains into the westerly branch of the main Serpent River system.

Stanrock Uranium Mines Ltd. ceased operations in 1970. During the period of conventional mining operations (until 1964), tailings were discharged to an area south of the mill (Figure 2.1). The main decant from the area discharged southward into a chain of lakes which are connected to the Pecors Lake sub-basin (OWRC 1972). Barium chloride and lime are added to the tailings runoff at Moose Lake downstream of the tailings basin. Orient Lake now serves as a settling basin for the treated water from Moose Lake. From Orient Lake, water flows to May Lake and thence to Hough and Pecors Lake (Bowman 1984).

2.1.3 Water Quality

Recent water quality data from the Serpent River system (Dunlop Lake to Depot Lake) were reviewed and selected parameters are shown in Table 2.2. The impact of uranium mill effluent can be seen in elevated total dissolved solids, ammonia, Ra-226 and U levels. The pH of receiving waters is somewhat elevated in the Serpent River downstream of Stollery Lake presumably due to the discharge of neutralized tailings effluent from the Denison and Quirke mines. From Quirke Lake down to Pecors Lake inlet, the pH shows a downward trend.

These recent water quality data show that the system is not as impaired as it was when studied in the late 1960's (OWRC 1972). In particular, Ra-226 levels have shown large decreases and now are usually only slightly elevated above 0.1 Bq/L (the drinking water criterion). Total dissolved solids remain elevated as does the ammonia level in the Stollery Lake - Quirke Lake reach of the system.

2.1.4 Sediment Quality

The 1972 OWRC study found increases over background levels of Ra-226 and gross alpha and beta activities in sediments of the lakes and stream downstream of the mining operations (Table 2.3). The levels decreased with increasing distance from the mines and elevated levels were confined to the top few centimetres of the sediments.

No recent sediment data are available.

2.1.5 Biology

The OWRC (1972) study of the Serpent River basin revealed that

primary production (due to planktonic algae) and zooplankton populations were greatly reduced in the Quirke and Pecors Lake sub-basins and part of McCarthy Lake. This was attributed to low concentrations of inorganic carbon due to low pH. Invertebrate species diversity was greatly reduced in the river portions of the affected area. Lake invertebrate diversity did not undergo comparable changes due to lower overall initial diversity. However, large clams did disappear from the Quirke and Pecors Lake areas. Fish population abundance, diversity, reproductive potential and condition were all reduced downstream of the mines, particularly in Quirke, Whiskey and Pecors Lakes.

Since the OWRC study, little work has been done on any biological component of the Serpent system. Since water quality has improved, one would expect some recovery of invertebrate and fish populations. A 1980 Ontario MOE survey of invertebrates from four stations in the upper Serpent River below Dunlop Lake showed large populations of caddisflies, elmid beetles and blackflies. Numbers decreased by a factor of 5-7 at the Serpent River inlet to Quirke lake (where ammonia levels are high) (MOE 1980).

Radionuclide levels in invertebrates from the Serpent system sampled in the late 1960's are summarized in Table 2.4. Clams and crayfish had the highest levels. Midges had relatively high levels throughout the sampling area, even in the "control" lake, Dunlop Lake. Caddisflies had lower overall levels, but showed a definite increase downstream of the mines.

2.2 Wollaston Lake Area

2.2.1 Hydrology and Limnology

Wollaston Lake is a large (40,592 ha) lake lying on the Precambrian Shield in northeast Saskatchewan (Figure 2.2). The

drainage of Wollaston Lake is through two outlets: one, the Fond du Lac River to Lake Athabasca; the other, the Cochrane River to Reindeer Lake and into the Churchill River system (Gulf Minerals 1980). The rate of flow is slow and the flushing time is estimated at 14 years (Gulf Minerals 1980).

The morphometry of the entire lake has been described by Rawson (1959). Collins, Pow and Hidden Bays, which are adjacent to the Eldor Resources uranium mining operations near the west shore of Wollaston Lake, were sampled in this study. The morphometry of these three bays is described in Table 2.5.

The study area receives drainage from two major streams. The Umpherville River drains Ahenakew Lake and the surrounding watershed into Hidden Bay. Collins Creek drains Lampin and Kewen Lakes into Collins Bay (Sawchyn 1973). Thirteen other streams also enter Hidden Bay, notably a stream draining Parks Lake, and Effluent Creek draining the Eldor tailings area. Two streams enter Pow Bay; one of these, Rabbit Creek, drains lakes which have received mine water. In addition to Collins Creek, seven small streams supply Collins Bay from the northwest (Sawchyn 1973).

Mean annual flow in the Umpherville River was estimated to be 10.1 m^3/s in 1972 (Sawchyn 1973). Collins Creek mean annual flow was estimated to be 9.9 m^3/s in 1972 and 6.0 m^3/s in 1979 (Sawchyn 1973, Gulf Minerals 1980). An estimated 11.9 m^3/s of water was estimated to be entering each of the three bays (Sawchyn 1973).

Water temperature profiles in the three study bays revealed that thermal stratification occurred on several occasions during the summer, but never became permanently established. Dissolved oxygen remained at or near saturation at all depths in the summer

and stayed well above the critical level for fish survival in the winter (Sawchyn 1973).

2.2.2 Uranium Mines in the Study Area

Uranium mining began in the area in 1974, with the development of Gulf Minerals' open pit mine at Rabbit Lake. The mine-mill complex is two miles west of Wollaston Lake. Rabbit Lake itself was drained as part of the mine development. The ore resources in the Rabbit Lake pit have now been exhausted.

Until 1977, seepage and surface runoff water that collected at the bottom of the pit were pumped directly to a natural drainage course which discharged via Rabbit Creek into Pow Bay. In 1977, diversion ditches were constructed to direct surface runoff away from the pit. At the same time, a holding pond was built to collect seepage water and pump it to the mill for use as process water (Robinson et al 1983). Tailings were neutralized and pumped to a tailings basin constructed by damming a large natural depression. Decant from this basin was treated with barium chloride. The effluent flowed through two settling ponds and then was discharged to Effluent Creek which flows into Hidden Bay (Robinson et al 1983).

A new ore-body, the "Collins Bay B-zone" is now being developed. This ore body is about six miles north of the Rabbit Lake operation and extends 500 ft. out into Collins Bay (Gulf Minerals 1980). A dyke has been built across the section of the bay overlying the ore-body, and de-watering and excavation are well underway. The mine is now owned by Eldor Resources Ltd.

2.2.3 Water Quality

General water quality in the three study bays is typical of

oligotrophic Precambrian Shield Lakes. Total dissolved solids levels are very low, alkalinity is low and due primarily to bicarbonates, nutrient levels are extremely low and often less than detection limits and trace elements are largely undetectable (Sawchyn 1973, Gulf Minerals 1980).

Selected water quality data from the pre-mining period (Sawchyn 1973) and more recent data are summarized in Table 2.6. Two systems have been obviously affected by mining operations, Rabbit Creek and Effluent Creek. The area of Hidden Bay near the mouth of Effluent Creek also shows some change in water quality. The major effects are increased total dissolved solids, ammonia, Ra-226 and U levels (Robinson et al 1983, Environment Saskatchewan 1984). In addition, Effluent Creek has had elevated arsenic, lead and nickel levels (Robinson et al 1983). Collins Bay water quality remains close to background levels.

2.2.4 Sediment Quality

Sediment radionuclide levels in Collins Bay are representative of background (Neame et al 1982) (Table 2.7). Both Ra-226 and U are elevated in selected sediments from Pow Bay and Hidden Bay and greatly elevated in the Rabbit Creek and Effluent Creek systems (Table 2.7). In the areas with elevated levels, higher readings are confined to the top 5 cm of sediment, indicating that the increased levels are recent in origin, corresponding with exploration and mining activity in the area (Neame et al 1982).

2.2.5 Biology

The phytoplankton community of the study area is dominated by Chrysophyta (yellow-brown algae) and Bacillariophyta (diatoms), typical of cold oligotrophic systems (Sawchyn 1973, Gulf Minerals 1980). There is lowered phytoplankton diversity and abundance in

Effluent Creek (Robinson et al 1983). There are insufficient data to allow comparison of plankton populations among the bays themselves or to detect changes with time.

Rotifers dominate the zooplankton community in the study area. Copepods and cladocerans also occur, but in lower numbers (Sawchyn 1973, Gulf Minerals 1980). Zooplankton were absent in Effluent Creek in 1978 and there was a reduction in zooplankton numbers in Hidden Bay near the mouth of Effluent Creek (Robinson et al 1983). Both numbers and diversity of zooplankton were lower in Pow Bay and Hidden Bay in 1978 compared with 1972 data (Robinson et al 1983).

The benthic invertebrate community is dominated by the amphipod Pontoporeia affinis. Sphaeriid clams, oligochaetes (worms) and chironomids (midge larvae) are also common (Sawchyn 1973, Gulf Minerals 1980). Invertebrate populations were low in Effluent Creek in 1978; oligochaetes and chironomids predominated (Robinson et al 1983). Diversity was reduced and density was greater at the mouth of Effluent Creek in 1978 (Robinson et al 1983).

The fish community in the three study bays is dominated by longnose suckers. Lake whitefish, northern pike and lake trout are also fairly common; while arctic grayling and walleye are relatively uncommon and confined to particular habitats (Sawchyn 1973, Gulf Minerals 1980). Cisco, burbot and round whitefish also occur and there are several species of forage fish present. The fish populations reflect available habitat and angling pressure; no relationships between fish diversity or abundance and proximity to mining effluent sources have been recorded. Fish growth rates are moderate and are usually comparable to those recorded by Rawson in 1949 and 1956 (Sawchyn 1973).

Radionuclides have been measured in aquatic macrophytes, insects and fish from the study area. Radionuclides in fish in 1972 and 1978 were all within background levels (Sawchyn 1973, Robinson et al 1983). Aquatic moss at the mouth of Rabbit Creek had elevated levels in 1978 (Robinson et al 1983). Recent biological monitoring data are summarized in Table 2.8. Submerged macrophytes, Potamogeton, Myriophyllum, and invertebrates contain consistently detectable levels of radionuclides; however, there are insufficient data for comparison among locations.

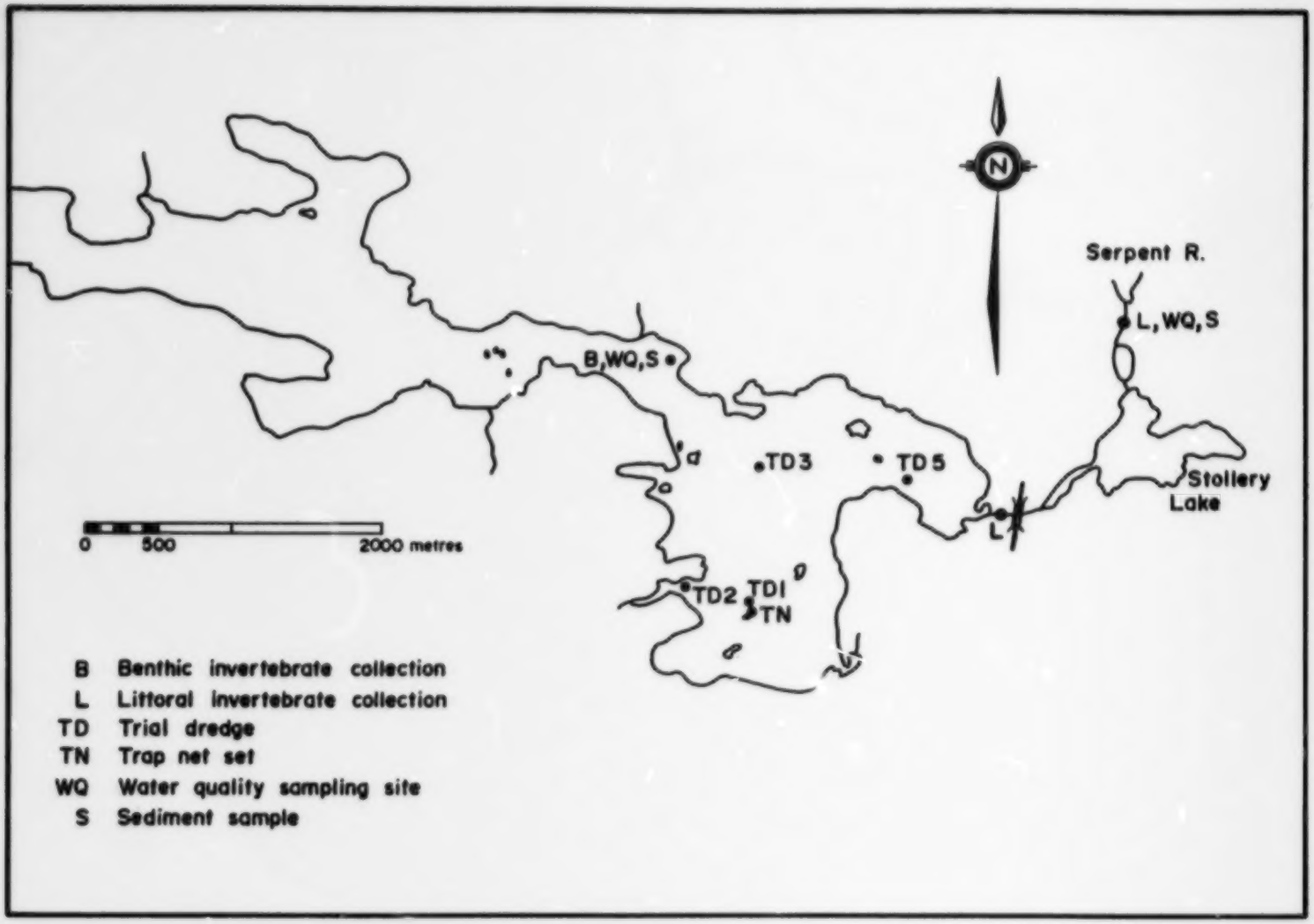


Figure 2.1 **ELLIOT LAKE STUDY AREA**

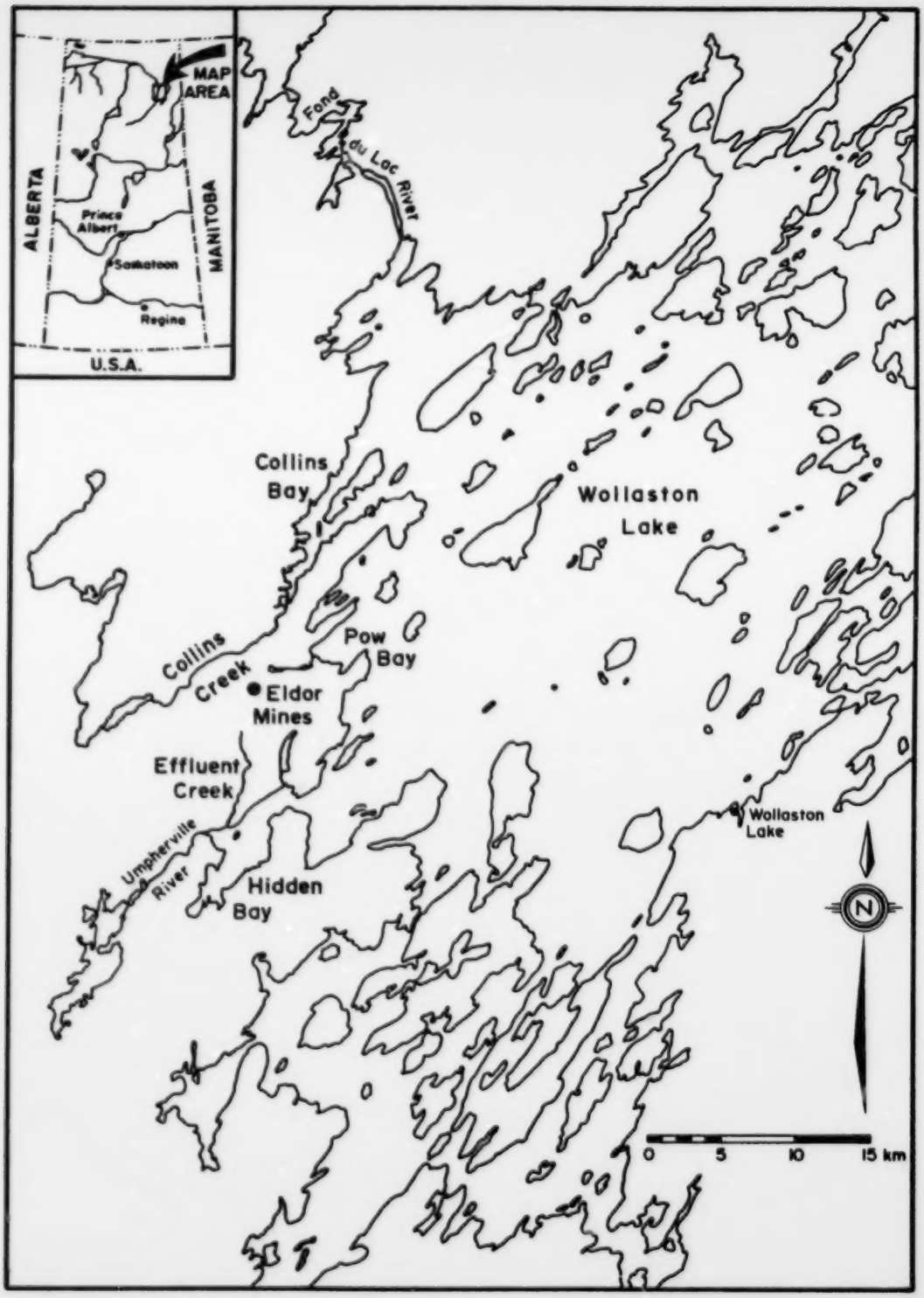


Figure 2.2 **WOLLASTON LAKE STUDY AREA**

Table 2.1

MORPHOLOGICAL DATA FOR THREE OF THE LAKES SAMPLED
(FROM MACLAREN 1977)

Lake	Volume ($m^3 \times 10^6$)	Surface Area (hectares)	Mean Depth (m)	Maximum Depth (m)
Dunlop	100.7	1098	9	55
Quirke	-	2097	-	100+
Depot	-	184	8	20

Table 2.2

SUMMARY OF SELECTED WATER QUALITY DATA FROM ELLIOT LAKE AREA; ALL VALUES ARE MEANS

Location	Sampling Agency	Year	pH	Ra-226 mBq/L Dissolved	U ug/L Total	NH_3-N mg/L	Total P mg/L	TDS mg/L	Conductivity umhos/cm	Heavy Metals With Levels Higher Than Usual*
Dunlop L. (control)	Rio Algom	1980	6.4	74	-	-	-	33	-	-
		1981	6.4	48	10	0.45	-	26	-	-
	Ontario M.O.E.	1980	7.1	37	<10	0.11	-	22	-	-
Serpent R. at Dunlop L.	Ontario M.O.E.	1980	7.2	37	5	-	0.006	-	-	Co,Zn,Cu
		1981	6.8	-	5	-	0.03	-	49	-
		1982	7.1	-	1	0.06	0.01	-	37	-
		1983	7.0	-	5	0.03	0.01	-	109	-
Serpent R. at Stollery L. outlet	Denison	1980	8.8	85	-	43	0.07	2937	-	-
		1981	8.7	126	-	42	0.12	3029	-	-
Serpent R. at inlet to Quirke L.	Rio Algom	1980	7.5	148	-	11.0	-	907	-	-
		1981	7.4	111	20	16.9	-	1220	-	-
	Ontario M.O.E.	1980	7.5	74	33	14.3	0.008	1156	-	Co
		1981	7.4	137	69	15.6	0.025	1817	-	-
		1982	7.1	129	34	14.4	0.03	1095	-	Pb
		1983	7.1	132	14	10.4	0.01	1080	-	-
Quirke L. at Panel Pumphouse	Rio Algom	1980	5.9	185	-	3.0	-	285	-	Co,Pb
		1981	5.8	133	-	3.1	-	302	-	Co,Cu,Pb
Quirke L.	Denison	1980	6.1	78	-	2.2	-	250	-	Co
		1981	6.0	100	-	3.0	0.03	317	-	-
Quirke L. SW of Stanrock	Ontario M.O.E.	1980	6.0	111	<10	2.9	0.008	269	-	Co

cont'd

Table 2.2 cont'd

Location	Sampling Agency	Year	pH	Ra-226 mBq/L Dissolved	U ug/L Total	NH_3-N mg/L	Total P mg/L	TDS mg/L	Conductivity umhos/cm	Heavy Metals With Levels Higher Than Usual*
Quirke L. outlet	Rio Algom	1980	5.5	185	-	2.9	-	-	-	Co
		1981	5.7	141	-	3.3	-	300	-	Ni,Zn
Pecors L. inlet	Rio Algom	1980	5.1	222	-	0.7	-	137	-	-
		1981	5.7	189	-	1.1	-	154	-	-
	Denison	1980	6.0	189	-	<1	-	113	-	-
		1981	5.8	167	-	<1	-	127	-	-
	Ontario M.O.E.	1980	6.5	111	10	0.56	0.001	128	-	-
Pecors L. outlet	Rio Algom	1980	5.2	159	-	1.2	-	179	-	-
	Denison	1980	5.3	133	-	1.0	-	162	-	-
		1981	5.6	126	-	1.0	-	158	-	-
	Ontario M.O.E.	1980	6.6	74	10	0.75	0.001	144	-	Co
		1981	6.6	100	6	0.54	0.01	-	303	Cu
		1982	6.6	110	-	0.28	0.01	-	171	-
		1983	6.9	102	1	0.34	0.01	-	208	-
Esten L.	Ontario M.O.E.	1980	7.2	37	<10	0.013	0.033	105	-	Co
Depot L. outlet	Ontario M.O.E.	1980	7.0	37	10	0.06	0.009	-	-	-
		1981	6.9	37	3	0.07	0.05	-	152	-
		1982	7.2	50	2	0.07	0.02	-	181	-
		1983	6.9	-	1	0.07	0.02	-	177	-

*Based on Environment Canada records from natural surface waters (McNeely et al. 1979)

Table 2.3

RADIONUCLIDE LEVELS IN SEDIMENTS FROM THE SERPENT RIVER BASIN (OWRC 1972); DREDGE RESULTS

Location	Ra-226 (Bq/g (dry)) mean	U-238 (ug/g (dry)) mean
Dunlop Lake	0.07	4.7
Quirke Lake	0.58	86
Whiskey Lake	0.47	23
Pecors Lake	0.69	18
McCarthy Lake	0.19	14.5
Elliot Lake	0.56	58
Depot Lake	0.20	14

Table 2.4

RADIONUCLIDE LEVELS IN INVERTEBRATES IN THE SERPENT RIVER BASIN (OWRC 1972)

Species	Location	Ra-226 Bq/g dry	U ug/g dry
Clams (Unionidae)	McCarthy L.	15.5	57
	Serpent R. Harbour	5.9	20
Caddisfly larvae	Below Dunlop L.	0.04	-
	Inlet to Quirke L.	0.74	-
	Outlet of Quirke L.	0.19	-
	Inlet to Whiskey L.	0.30	-
	Outlet of Whiskey L.	0.48	-
	Inlet to Pecors L.	0.44	-
	Outlet of Pecors L.	0.27	-
	Downstream of Depot L.	0.27	-
Crayfish	Below Dunlop L.	0.07	-
	Outlet of Quirke L.	1.7	36
	Inlet to Whiskey L.	1.4	5
	Outlet of Whiskey L.	0.96	-
	Downstream of McCarthy L.	2.6	3
Midges	Dunlop L.	1.1	-
	Quirke L.	0.92	-
	Serpent R. between Quirke L. and Whiskey L.	2.1	-
	Pecors L.	1.3	-
	Elliot L.	1.0	-
	Depot L.	0.93	-
	Downstream of McCarthy L.	2.4	-
Worms	Elliot L.	0.93	160

Table 2.5

MORPHOLOGICAL CHARACTERISTICS OF THE SASKATCHEWAN STUDY AREA (SAWCHYN 1973)

Location	Volume ($\times 10^6 m^3$)	Volume Development	Surface Area (hectares)	Shore Length (km)	Shore Development	Mean Depth (m)	Maximum Depth (m)
Collins Bay	150.1	0.627	2697	46.0	4.62	5.6	25
Pow Bay	122.5	0.828	1054	12.3	1.96	11.6	42
Hidden Bay	144.0	1.074	2099	38.6	3.09	6.8	19

Table 2.6

SELECTED WATER QUALITY DATA FROM THE WOLLASTON LAKE AREA; ALL VALUES ARE MEANS

Location	Source of Data	Year	pH	Ra-226 mBq/L (total)	U ug/L (total)	NH_3-N mg/L	Total P mg/L	TDS mg/L	Conductivity umhos/cm	Heavy Metals With Levels higher than usual*
Collins Bay	Sawchyn (1973)	1972	6.7	n.d.**	n.d.	-	<0.01(PO_4)	14	21.8	-
		1973	6.6	-	-	0.09	0.022(PO_4)	34	27.4	-
	Gulf Minerals (1980)	1979	6.7	<3.7	0.30	0.04	<0.02	30	-	-
	Env. Saskatchewan	1984	6.3	<8.0***	<1.1***	<0.10	<0.01 (PO_4)***	70	23.6	-
Collins Cr.	Robinson et al (1983)	1978	-	<3.7	80	0.59	0.01	-	15	-
Pow Bay	Sawchyn (1973)	1972	6.9	<4.8***	<2.04***	-	<0.01(PO_4)	12	22.9	-
		1973	7.0	-	-	0.05	0.021(PO_4)	26	26.3	-
	Robinson et al (1983)	1978	-	<3.7	<60	0.13	<0.03	-	26.3	-
	Env. Saskatchewan	1984	7.0	<56.8***	7.0	<0.10	<0.01(PO_4)	-	36.4	-
Rabbit Cr.	Robinson et al (1983)	1978	-	196	230	0.17	0.04	-	85	-
Hidden Bay	Sawchyn (1973)	1972	6.9	n.d.	<0.50***	-	<0.01(PO_4)	13	22.8	-
		1973	6.6	-	-	0.07	0.26(PO_4)	30	29.0	Cu
	Robinson et al (1983)	1977	7.2	-	-	0.06	-	45	31	-
		1978	7.3	<3.7	<60	0.39	<0.01	-	44.7	-
	Env. Saskatchewan	1984	6.9	<9.3***	<2.5***	<0.13***	0.01(PO_4)	-	49.3	-
Hidden Bay Near Effluent Creek Mouth	Robinson et al (1983)	1977	7.4	66.7	-	12.2	-	257	384	-
Effluent Cr.	Robinson et al (1983)	1977	7.7	259	-	201	0.10	5910	6040	-
		1978	6.4	61.9	<60	114	<0.01	-	3300	As,Pb,Ni

*based on Environment Canada data on natural surface waters (McNeely et al 1979)
** n.d. = not detectable
*** some readings were not detectable

Table 2.7

MEAN RADIONUCLIDE LEVELS IN SEDIMENTS IN THE THREE STUDY AREAS (WOLLASTON LAKE)

Location	Source of Data	Ra-226 Bq/g dry	U ug/g dry
Collins Bay	Neame et al (1982)	<0.005*	2.9*
Pow Bay	Sawchyn (1973)	0.28**	156**
	Robinson et al (1983)	0.07	8.6
Rabbit Creek drainage	Sawchyn (1973)	0.12	79.4
	Robinson et al (1983)	16.9	1801
	Neame et al (1982)	3.1*	1033*
Hidden Bay	Sawchyn (1973)	0.08	6.5
	Robinson et al (1983)	0.11	8.5
	Neame et al (1982)	0.05*	176.2*
Effluent Cr.	Robinson et al (1983)	0.08	62.4

* some Ra-226 readings in these data sets are less than detection limits. These values (U or Ra-226) are means of readings from several depths within a sediment core.

** one value only

Table 2.8

MEAN RADIONUCLIDE LEVELS IN MACROPHYTES AND INVERTEBRATES FROM THE WOLLASTON LAKE AREA

Location	Date	Source	Species	Ra-226 Bq/g dry wt.	U ug/g dry wt.
Hidden Bay	1981	MPCB*	Carex spp.	≤0.002**	≤0.4**
	1981	MPCB	Sparganium spp.	≤0.002**	2.3**
Pow Bay	1981	MPCB	Carex spp.	≤0.002**	≤0.4**
	1981	MPCB	Sparganium spp.	≤0.002**	≤0.4**
Collins Bay	1979	Gulf Minerals (1980)	Carex spp.	0.007	-
			Potamogeton sp.	0.496	-
			Equisetum fluviatile	0.007	-
			Polygonum amphibia	0.002**	-
			Nuphar sp	0.003	-
			Sparganium spp.	0.050	-
			Isoetes spp.	0.219	-
			Myriophyllum, Potamogeton, + Ranunculus	0.62	-
			Caltha palustris	0.013**	
Collins Bay	1979	Gulf Minerals (1980)	Diptera	0.042	-
			Trichoptera	0.148**	-
			Trichoptera + Ephemeroptera	0.074**	-
			Amphipoda	0.110	-
			Pelecypoda	0.031	-

* Saskatchewan Environment Mines Pollution Control Branch monitoring data

** single point data - not a mean

3.0 METHODS

3.1 Field Methods

The three main objectives of the field program were to:

1. Find suitable sites within each lake, bay or stream where sufficient invertebrate populations existed; collect as many replicate invertebrate samples as possible.
2. Collect water and sediment samples at each main invertebrate site.
3. Collect fish at each site, examine their stomach contents and save some specimens for possible radionuclide analysis.

In the Elliot Lake area, a review of Ontario Ministry of Environment (MOE) water quality data was used to aid selection of specific sites. On the basis of these data, Dunlop Lake, which is upstream of all mining activity, was selected as a control. The remaining sites chosen, in order of decreasing contamination were: Serpent River downstream of Stollery Lake, Quirke Lake, Pecors Lake and Esten Lake.

In the Wollaston Lake area, Collins Bay and Collins Creek were selected as control sites (based on water and sediment quality data). The remaining sites were the mouth of Effluent Creek, Hidden Bay and Pow Bay.

At each site, a mid-lake or mid-stream sampling station was selected. At this station, invertebrate, sediment and water samples were colleced (Figures 3.1-3.6). Additional invertebrate samples were taken from near-shore (littoral) areas in the lakes to augment the number of samples. Sediment and water samples were not taken from these near-shore areas due to budgetary constraints. Fish samples were taken from several areas within

each lake, including the area close to each mid-lake sampling station.

There was one exception with respect to the selection of the main sampling station. In Quirke Lake, all mid-lake stations were devoid of invertebrates. Therefore, a nearshore station was used as the main station, at the mouth of a small creek (Figure 3.2). The water quality from this station may not, therefore, be representative of the lake proper.

In addition to the 5 Ontario and 5 Saskatchewan sites listed above, 3 additional sites were sampled to augment the invertebrate collections. These were, in Ontario, the Serpent River immediately downstream of Dunlop Lake and the Serpent River immediately downstream of Pecors Lake, and, in Saskatchewan, the mouth of the Rabbit Creek as it enters Pow Bay. These 3 sites were sampled for invertebrates only, again because of budgetary constraints.

All invertebrate collection sites are noted on the detailed maps (Figures 3.1-3.6). In the lakes, invertebrates were collected by Ekman grab at the deeper "main" stations and by dip net in shallow areas near shore. Stream insects were collected by dip net. Ekman samples were screened in the boat by placing the screens on two poles lashed across the boat and overhanging the water. Once a good location was found, repeated Ekman or dip net samples were taken, screened and sorted until a sufficient amount of material was obtained or time ran out. Invertebrate samples were sorted according to subfamily or genus in the boat. Each evening, the samples were further sorted (to the genus level except for oligochaetes and some midge larvae), washed gently in distilled water and frozen. Additional samples of all invertebrates encountered were preserved in alcohol for later identification.

Triplicate sediment samples were taken at each main sampling station. The sample consisted of the top 4 cm of the Ekman sample. Stream sediments were collected by manually scooping up the bottom material. Samples were placed in plastic bags and frozen as soon as possible.

Water samples were taken using a Kemmerer sampler; three replicates for radionuclides, one sample for major ions, one for trace elements and one for nutrients (Figures 3.1-3.6). Water from 0.5 m above the bottom was collected to represent the environment experienced by benthic invertebrates. Each of the three water samples collected for radionuclide analysis was split into two: one was filtered through a 0.45 u membrane filter, the other left unfiltered. These water samples were preserved with nitric acid immediately after collection.

Water samples for nutrient analysis were preserved with sulphuric acid and samples for trace element analysis were preserved with nitric acid. Samples for major ion samples were untreated. Temperature, oxygen, conductivity, pH and alkalinity were measured in the field.

Forage fish were sampled to obtain data on food habits and also to save for possible radionuclide analysis. These fish were collected by beach seine. The fish were sorted into species and frozen.

Large fish were collected by 3" or 5" gill net, except in Dunlop and Pecors Lakes where trap nets were used because of fish stocking programs. Ten specimens per species (or as many specimens as were caught) were processed for possible radiochemical analysis. Each fish was weighed, measured, sexed and gutted. The stomach contents were removed and saved in

plastic bags. Aging materials (otoliths or pectoral fin rays) were taken. The fish and stomach contents were then frozen. In the Elliot Lake area, additional stomachs were taken and examined the same evening in order to aid in the selection of invertebrates for sampling (see Appendix II).

3.2 Laboratory Methods

All analyses were done by the Saskatchewan Research Council (SRC) analytical laboratory. Major ions and nutrients in water samples were analysed using techniques described in APHA (1980). Trace elements were determined using plasma emission spectroscopy, except for arsenic, bismuth, silica and tin which were determined by atomic absorption spectroscopy. Radionuclide samples were prepared and analysed using the procedures outlined in Table 3.1 (HASL 1972, CANMET 1979). A blank sample (distilled water in a randomly selected sample bottle) was also analyzed for all constituents listed above.

Before they were sent for analysis, invertebrate samples were checked and any uncertain identifications verified. Stomach contents were thawed, the contents identified and the percent of the total content taken by each item noted. The samples were then re-frozen and sent for analyses.

3.3 Computational and Statistical Methods

3.3.1 K_d and BF Calculations

Distribution coefficients (K_d) for water-sediments were calculated for each sample using the formula:

$$K_d = \frac{\text{Bq/g wet weight of sediment}}{\text{Bq/ml (total) in water}}$$

Bioaccumulation factors (BF) were calculated using the formula:

$$BF = \frac{\text{Bq/g wet weight of invertebrate}}{\text{Bq/g wet weight of sediment}}$$

or

$$BF = \frac{\text{Bq/g wet weight of invertebrate}}{\text{Bq/ml (total) in water}}$$

Means of 3 replicate water and sediment samples per site were used. If values for Ra-226 or U were less than detection limits, the value between 0 and the detection limit was used to compute the mean Ra-226 or U levels. Standard errors of the mean were used to compute upper and lower ranges for the K_d's and BF's.

The BF calculations for the additional invertebrate stream collection sites in Ontario were done using water and sediment data from the nearby lake sites. The quality of water discharged from the lakes was very similar to the quality in the streams (Tables 2.2 and 4.1). The additional Rabbit Creek mouth site in Saskatchewan had elevated water and sediment radionuclide levels (Table 2.7); therefore, 1984 monitoring data from Saskatchewan Environment were used for BF calculations for this site.

3.3.2 Selection of Statistical Methods

Statistical analyses of the data in this report were done to investigate the possible relationships between environmental parameters and the Ra-226 and U levels, K_d's and BF's that were found.

Basic statistics (means, standard deviations, standard errors) and normality tests on sediment and invertebrate data were

performed using procedure UNIVARIATE of the SAS (SAS 1982) statistical software package. The results of the normality tests indicated that the use of further parametric tests was appropriate, providing the data were logarithmically transformed to remove heterogeneity of variances.

Analysis of variance (ANOVA) was performed on sediment and invertebrate data in order to determine whether Ra-226 or U levels, K_d's or BF's differed significantly among sites, sediment type, habitats or "feeding type". A factorial ANOVA for unbalanced data (i.e. unequal numbers of replicates within "treatments" or "classes") was run. Procedure GLM (General Linear Model (SAS 1982)) was used.

The ANOVA determined whether there were overall differences in the observed Ra-226 and U levels, K_d's and BF's among sites, sediment types and other factors. In order to identify the specific mean values of Ra-226 or U levels, K_d's and BF's that differed significantly from each other the Student-Newman-Keuls test (Procedure S-N-K of SAS) was run after each ANOVA procedure.

To supplement the information provided by ANOVA and the S-N-K tests, the multivariate statistical method called Principal Components Analysis (PCA) was used. PCA is used for summarizing data and for detecting linear relationships when several parameters vary at the same time (SAS 1982). PCA can also prove useful in guiding the researcher in how to minimize the number of variables required in a regression analysis. PCA is a variance oriented method of analysis which requires no hypotheses about the variables. The principal components are new variables, specifically linear combinations of the original variables. The variance is partitioned among the principal components such that the first principal component accounts for the largest fraction of the variance that can be accounted for by a linear combination

of the data, the second principal component is the linear combination of variables which accounts for the next largest fraction of the variance (subject to being orthogonal to and uncorrelated with the first principal component) etc. While the PCA method has proven to be robust in various ecological applications (eg. Orloci 1978, Gauch 1982), it should be emphasized that PCA is an exploratory statistical tool. There is no guarantee that PCA will uncover the "true" generating processes or causal agents. Rather, PCA allows one to pick out major changes in variability in the dataset. Most of these changes are likely to have been caused by, or at least to have arisen indirectly from, environmental changes (Harris 1975, Williamson 1972). As pointed out by Harris (p. 163, 1975) "the gain in interpretability of results will, however, be illusory if the uncorrelated variables (i.e. the principal components) do not themselves have simple substantive interpretations."

Procedure PRINCOMP (SAS 1982) was used to run the PCA.

3.3.3 Application of Statistical Methods

The ANOVA and S-N-K test on sediment data compared Ra-226 and U levels and K_d's among the 10 sample sites and by loss on ignition, iron content and manganese content "classes". The classes were defined as shown in Table 3.2.

The ANOVA and S-N-K test on invertebrate data compared Ra-226 and U levels and BF's among all sample sites and among "feeding type" classes. Invertebrates had to be classified according to feeding type rather than by genus because there were very few genera in common among sample sites. The "feeding type" classes and the category assigned to each invertebrate genus are shown in Table 3.3.

Principal components analysis (PCA) for water was performed on a data matrix consisting of analysis results of 39 analytes (the "attributes") over ten sample sites, two regions (1=Sask., 2= Ontario) and the 5 "habitat types" shown in Table 3.4.

Sediment PCA was performed on a data matrix consisting of Ra-226 and U levels and K_d's, loss on ignition, % moisture, iron and manganese results against region, sample site, habitat (Table 3.4) and "sediment type" based on a combination of sediment features as noted in the field (Table 3.5).

Invertebrate PCA was performed on a data matrix consisting of Ra-226 and U levels and BF's against region, sample site, habitat (Table 3.4), sediment code (Table 3.5) and feeding type (Table 3.3).

Interpretation of the PCA's was based upon the correlation of attributes (e.g. radionuclide levels) with the various principal components. The highest correlations or "eigenvectors" for each component were used. The clusters of sample sites, habitat types, etc., that appeared on the plots of the principal components could then be related to specific attributes, depending upon their relative position along each principal component (see Figures 4.1 to 4.3). The cumulative percent of data availability accounted for by each principal component was also used in the interpretation.

The same method of interpretation was used for water, sediment and invertebrate PCA's.

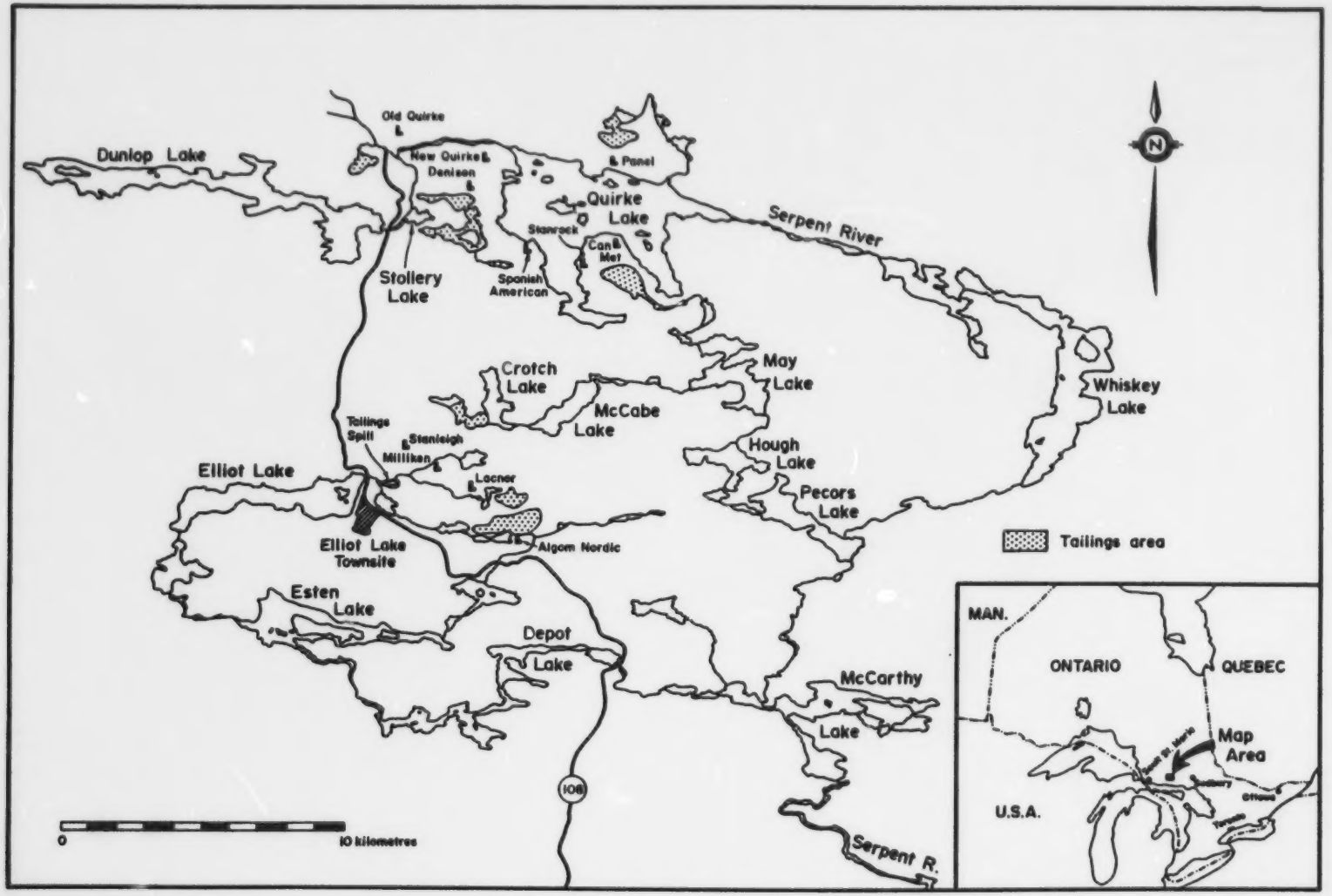


Figure 3.1 **DUNLOP LAKE AND SERPENT RIVER/STOLLERY SAMPLING SITES**

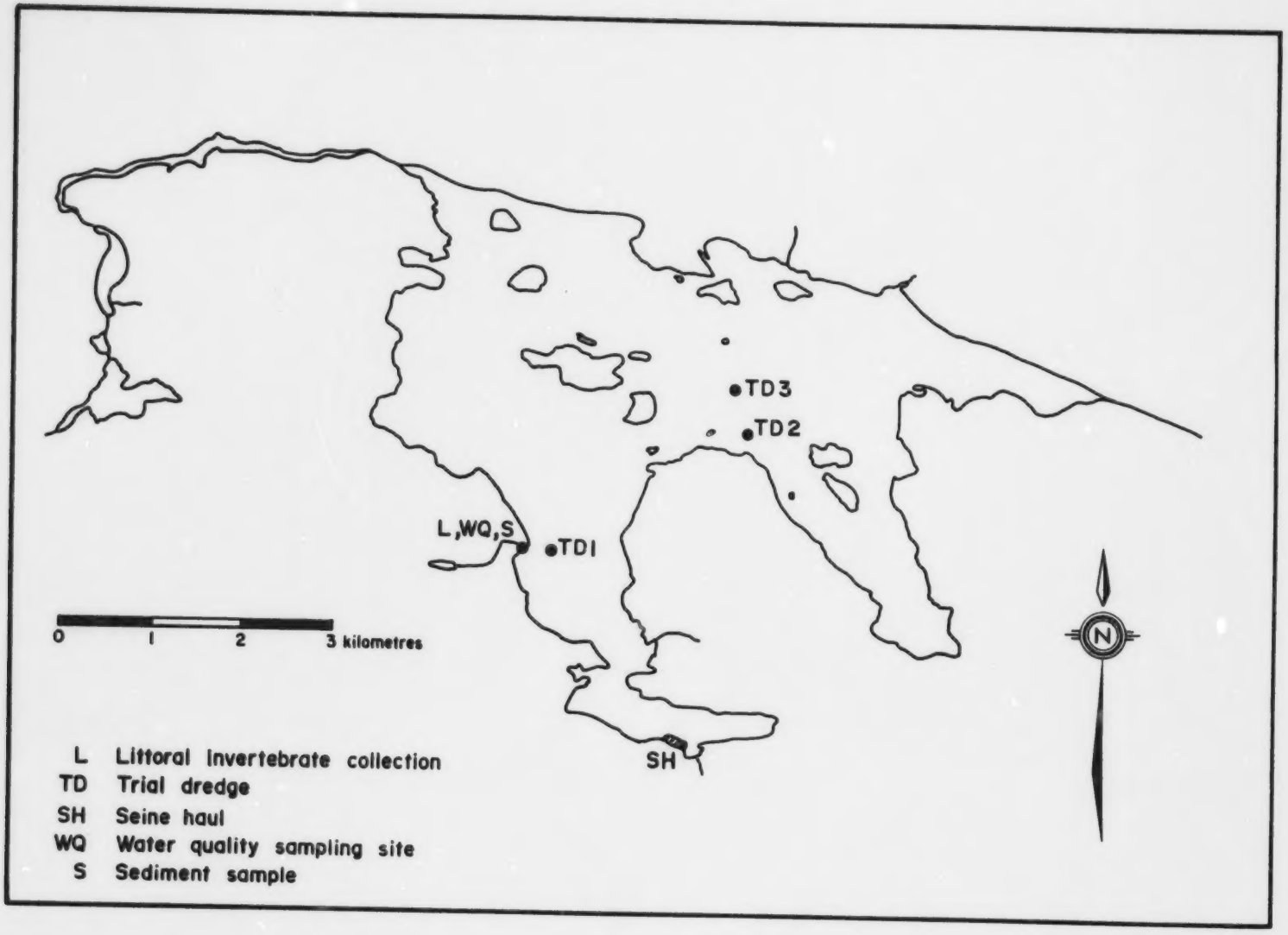


Figure 3.2 **QUIRKE LAKE SAMPLING SITES**

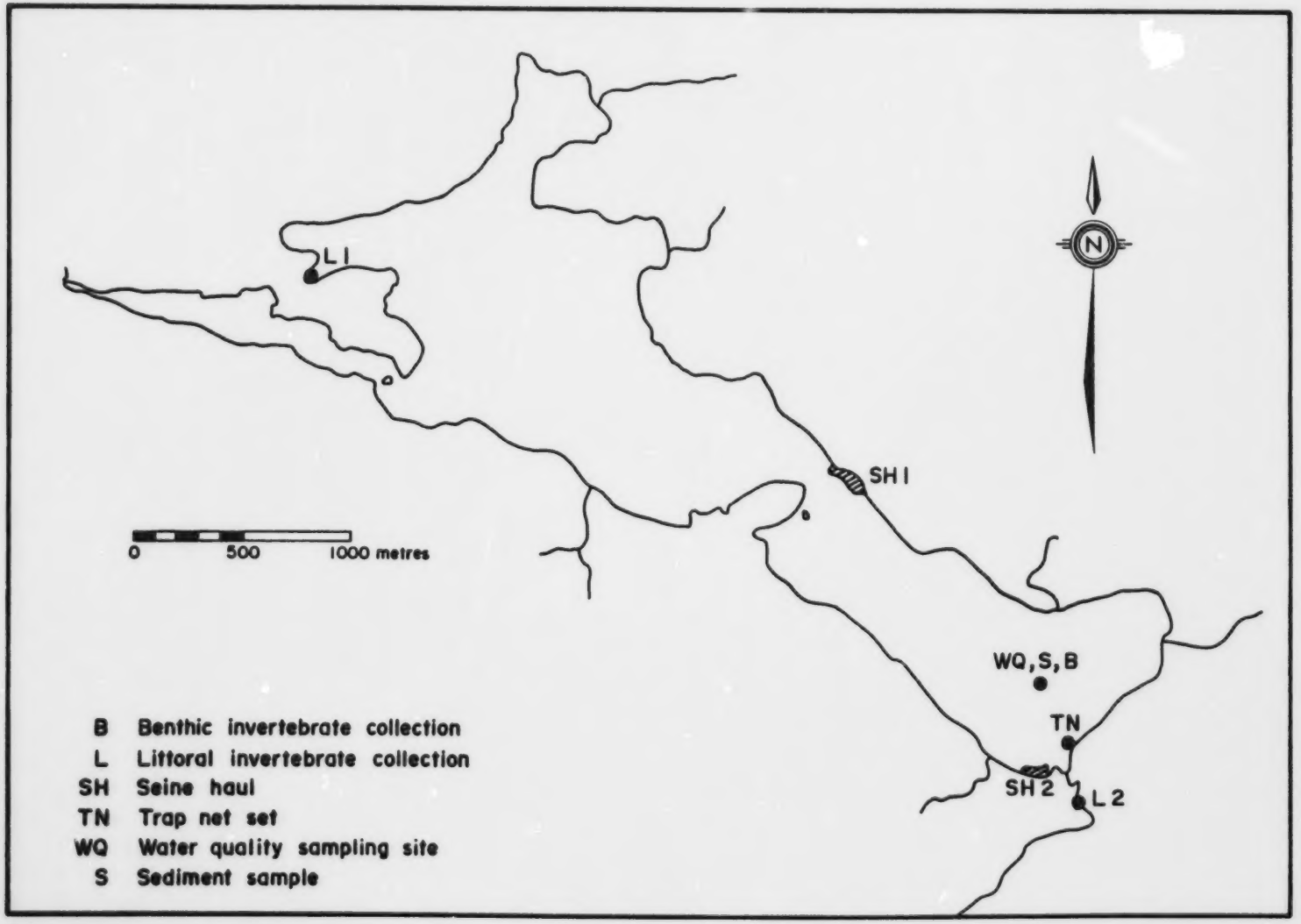


Figure 3.3 **PECORS LAKE SAMPLING SITES**

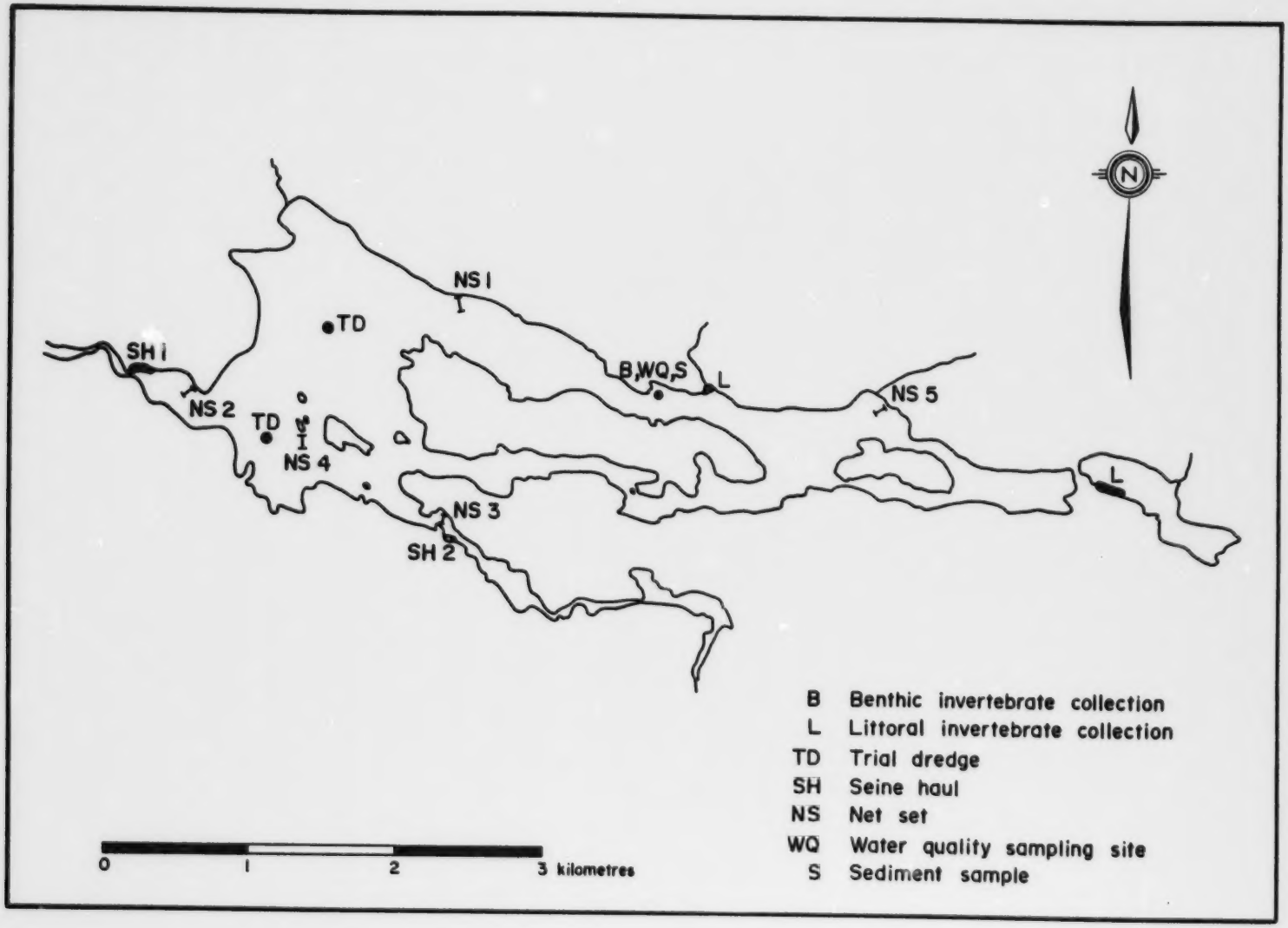


Figure 3.4 **ESTEN LAKE SAMPLING SITES**

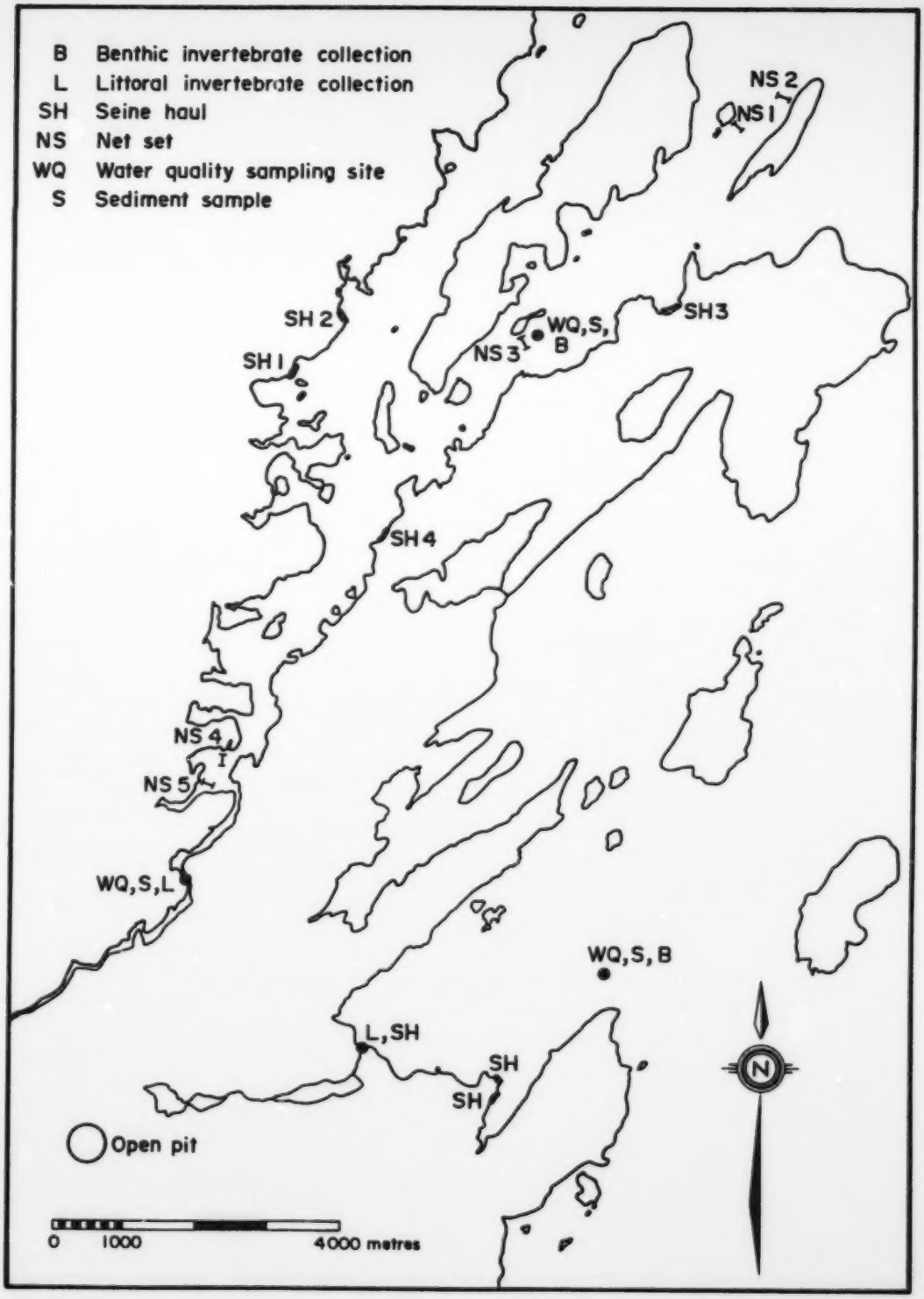


Figure 3.5 **COLLINS BAY AND POW BAY SAMPLING SITES**

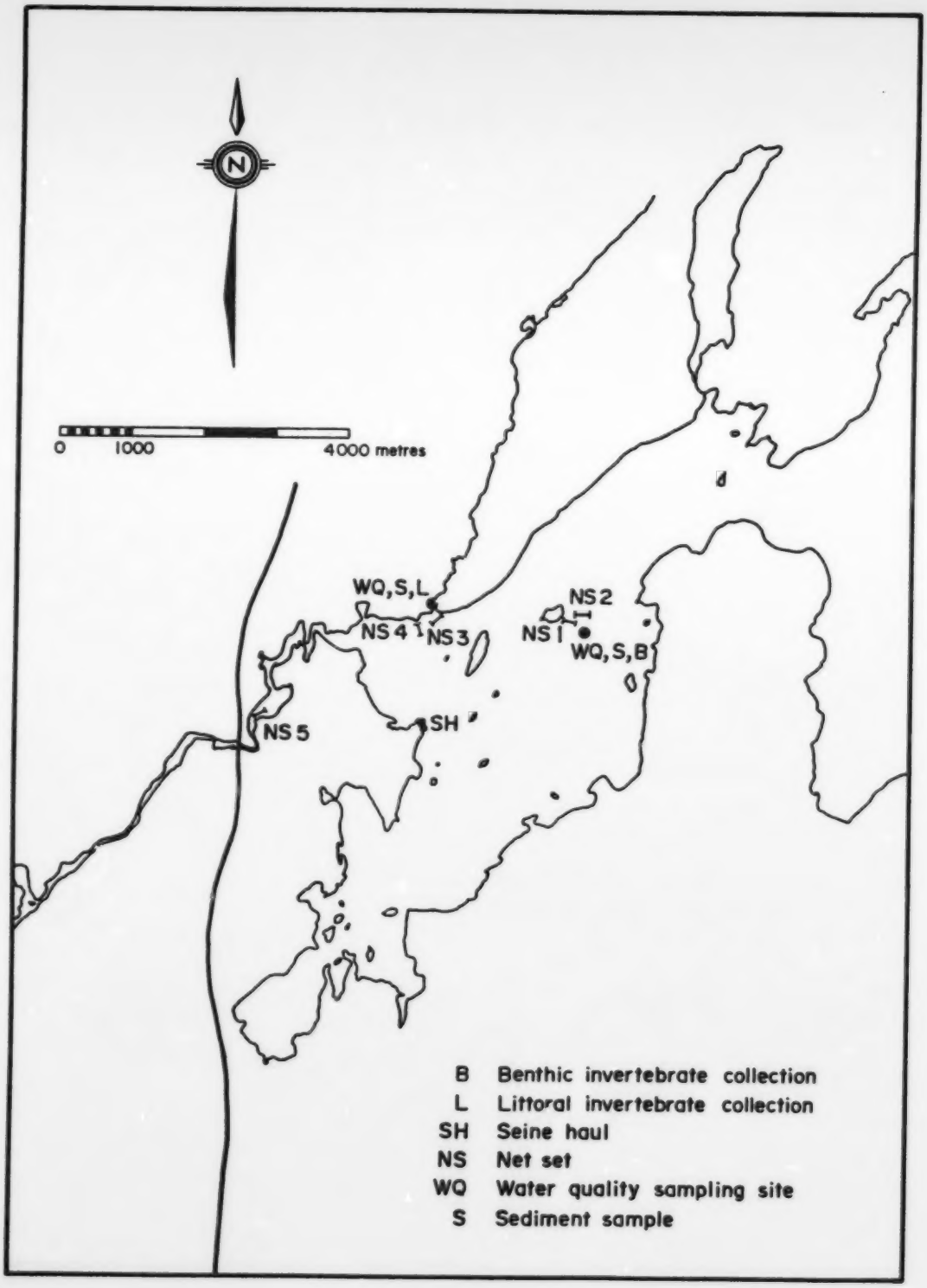


Figure 3.6 **HIDDEN BAY SAMPLING SITES**

Table 3.1

SAMPLE PREPARATION AND ANALYTICAL PROCEDURES FOR RADIONUCLIDE DETERMINATIONS

Radionuclide	Sample Type	Sample Preparation	Analytical Method	Detection Limit	Precision
Ra-226	water	acid-fixed in field	Precipitation as $Ba(Ra)SO_4$ and alpha spectometry	0.005 Bq	± 10-100% from 0.005 to 0.2 Bq ± 10% above 0.2 Bq
	sediment	pyrosulfate fusion			
	invertebrate or stomach contents	nitric-perchloric acid dissolution			
	fish	dry ashed (500°C)			
Total U	water	acid-fixed in field	Fluorometry (control samples)	0.001 ug	± 20-50% near detection limit
	sediment	aqua-regia/ perchloric acid dissolution			
	invertebrate or stomach contents	nitric-perchloric acid dissolution	Delayed neutron counting (contaminated samples)	0.01 ug	± 5-30% from detection limit to 30 ug ± 1-5% above 30 ug
	fish	dry ashed (500°C)			

Table 3.2

SEDIMENT CLASSES USED IN ANOVA PROCEDURE

Loss on Ignition		Iron Content		Manganese Content	
Range	Class	Range	Class	Range	Class
1-7%	1	1-10 mg	1	0.1-0.5 mg	1
8-14%	2	11-20 mg	2	0.5-1 mg	2
15-21%	3	21-30 mg	3	1-4 mg	3
22-28%	4	31-50 mg	4	5+ mg	4
		51+ mg	5		

Table 3.3
Feeding Type Classes and Classes Assigned to Invertebrate Genera

A. Feeding Type Classes

Filter Feeders	1	Detritivores	4
Herbivores	2	Omnivores	5
Carnivores	3		

B. Classes Assigned to Genera

Genus	Common Name	Feeding Type
Hydropsyche	Caddisfly	1
Cheumatopsyche	"	1
Wormaldia	"	1
Simulium	Blackfly	1
Ephemerella	Mayfly	2
Hexagenia	"	2
Gyraulus	Snail	2
Ophiogomphus	Dragonfly	3
Leucorrhinia	"	3
Aeschna	Dragonfly	3
Basiaeschna	"	3
Cordulegaster	"	3
Ryachophila	Caddisfly	3
Enallagma	Damselfly	3
Paragnetina	Stonefly	3
Acroneuria	"	3
Procladius	Midge	3
Pentaneura	Midge	3
Dytiscus	Beetle	3
Hirudinea	Leech	3
Pontoporeia	Water scud	4
Grammotaulius	Caddisfy	4
Nemotaulius	"	4
Chironomus	Midge	4
Glyptotendipes	"	4
Endochironomus	"	4
Orthocladinae	"	4
Chironomidae	"	4
Orconectes	Crayfish	4
Oligochaetes	Worms	4
Agrypnia	Caddisfly	5
Platycentropus	"	5
Anabolia	"	5
Limnephilus	"	5
Lenarchus	"	5
Phryganea	"	5

Table 3.4
Habitat Classes Used in PCA

Habitat	Class Code
Profundal	1
Littoral	2
Small Stream, Normal Flow	3
Stream through bog	4
Large stream, riffle	9

Table 3.5

SEDIMENT CODES USED IN PCA PROCEDURE

Description	Code
Mixed gravel	1
Boulders, gravel, sand	2
Sand	3
Rocks with silt and ooze between	4
Ooze over sand	5
Ooze over clay with iron concretions	6
Rocks, sticks, vegetation	7
Organic fine ooze	8
Organic ooze/fibrous debris	9
Organic ooze with oxidized layer	10
Organic fibres, some ooze	11

4.0 RESULTS

The description of results in the following sections is organized according to a standard format. First, an overall qualitative review of the data is presented. Second, trends identified qualitatively are examined using the analyses of variance (ANOVA) results. Third, Student-Newman-Keuls (S-N-K) test results are used to further confirm or elaborate upon the differences suggested by the ANOVA. Fourth, principal components analysis (PCA) results are described, related to trends already identified, and explored for additional information (particularly clustering) not revealed by either ANOVA or S-N-K.

4.1 Water Quality

Water quality parameters show the effects of proximity to uranium mill tailings effluent (Tables 4.1 and 4.2). Total dissolved solids and conductivity, the major cations and anions, nitrogen compounds and radionuclide levels are the parameters most affected in both Ontario and Saskatchewan. The pH levels measured in the field were not significantly depressed at any of the downstream Elliot Lake sites nor in Wollaston Lake. Select trace metals were elevated somewhat in both the Elliot Lake and Wollaston Lake areas.

Water quality data were not analyzed using ANOVA or S-N-K because of the lack of replication for all but radionuclide samples.

The results of the principal components analysis for water are summarized in Table 4.3. The first principal component (PRIN1) accounts for about 46% of the total variance. With the second and third components (PRIN2 and PRIN3) constituting approximately 24 and 16% of the total variance, the first three principal components account for 85 to 86% of the total variance.

The weights representing the contributions of the original water quality parameters or attributes to the principal components are listed on the bottom half of Table 4.3. For example, the attributes which contribute the most to PRIN1 include calcium, chlorides, magnesium, sodium, sulphate, ammonia, nitrogen, total Kjeldahl nitrogen, cobalt, chromium, iron, manganese, molybdenum, titanium, vanadium and total dissolved solids. Most of the attributes listed above under PRIN1 comprise part of the overall attribute total dissolved solids (e.g. all the major cations and anions and the trace metals) or the nitrogen attributes (eg. ammonia, nitrogen and total Kjeldahl nitrogen). Hence, in the following discussion for PRIN1 only the attributes total dissolved solids and total Kjeldahl are mentioned. The attributes with the highest loadings to PRIN2 from Table 4.3 include potassium, the three phosphorus forms (inorganic, total and ortho), tin, and dissolved and total radium-226. The attributes phosphorus and tin, in this instance, are artifacts of the analysis as all measured values were less than the detection limits. Hence only potassium and radium-226 are discussed with reference to PRIN2. The attributes contributing most to the remaining principal components include: aluminum, copper, nickel, lead and zinc to PRIN3; total organic carbon, barium and silica to PRIN4; bicarbonate alkalinity, nitrite plus nitrate nitrogen, dissolved and total uranium to PRIN5; and, barium to PRIN6.

The PCA plots shown on Figures 4.1 and 4.3 show clustering by sample site and region. A distinct cluster of Effluent Creek samples (location F) formed on all plots due to high total dissolved solids and total Kjeldahl nitrogen (Figures 4.1 to 4.3). Pecors Lake, Quirke Lake and Serpent River/Stollery Lake samples clustered according to elevated levels of Ra-226, potassium and total Kjeldahl nitrogen (Figure 4.1). Quirke Lake

samples (location N) formed a distinct cluster due to elevated heavy metals (Figure 4.3). Esten Lake and Serpent River/Stollery Lake samples separated out due to higher alkalinity, nitrite plus nitrate nitrogen, and/or U levels (Figure 4.3). Collins Bay and Quirke Lake also clustered according to alkalinity and/or U (Figure 4.3).

Comparison of plots of sample site, region and habitat suggest that sample site was the over-riding factor with respect to water quality (Figures 4.1 and 4.2). The clusters of regions and habitat types are virtually identical to the sample site clusters. The mixing of types within the habitat clusters indicate that sample site was the more important parameter. The region clusters indicate that Ontario sites have higher overall Ra-226 and/or potassium levels than Saskatchewan sites (Figure 4.1) and slightly higher silica levels than Saskatchewan sites (component 4, Table 4.3, plot not shown). Saskatchewan sites had slightly higher total organic carbon levels than Ontario sites (component 4, plot not shown).

4.2 Sediments

Sediment radionuclide levels reflect proximity to tailings effluent. Radium-226 and U levels in sediments were elevated at all Ontario sites downstream of Dunlop Lake and at the Hidden Bay and Effluent Creek sites at Wollaston Lake (Table 4.4).

Other sediment parameters do not appear to vary with distance from tailings effluent. Rather, they may reflect local habitat conditions such as depth and flowrate.

Distribution coefficients (K_d's) for all sites are high, particularly for Esten Lake, Collins Creek and Pow Bay (Table

4.5). These three sites also have the greatest range between upper and lower extreme values.

There is no consistent relationship either between K_d's and sampling site location or between K_d's and region (Ontario vs. Saskatchewan). Neither is there any apparent trend regarding Ra-226 or U K_d's; sometimes Ra-226 K_d's are higher whereas other times U K_d's are higher (Table 4.5).

Both Ra-226 and U K_d's are normally distributed ($p<0.01$) according to the Shapiro-Wilk statistic (SAS 1982).

Analysis of variance of Ra-226 and U levels and K_d's against sample site, percent loss on ignition, iron and manganese content showed that the U level was the only parameter which varied significantly with sample site. None of the other sediment parameters tested were found to be significant, according to ANOVA (Table 4.6).

Habitat type and sediment type (by field observation) could not be included in the ANOVA because of an excess of missing cells; i.e. a particular habitat or sediment type was often only represented by one site.

The differences in U levels with sample site may in part reflect proximity to tailings effluent. The S-N-K test showed 4 groups of significantly different sediment sample sites with respect to U levels. These are, in order of decreasing U content: (1) Effluent Creek/Quirke Lake/Pecors Lake; (2) Esten Lake; (3) Serpent River downstream of Stollery Lake/Hidden Bay; and (4) Pow Bay/Collins Bay/Dunlop Lake/Collins Creek (Table 4.7).

The S-N-K test also showed that U levels were highest in sediment with moderate organic content (8 to 14% L.O.I.), lower iron

(below 31 mg/g Fe) and low manganese levels (below 0.5 mg/g Mn) (Tables 4.8 to 4.10). These additional factors help explain the partial mixing of sites with respect to proximity to tailings effluent.

The S-N-K test showed signficantly higher Ra-226 levels in sediments with low iron content (below 31 mg/g) (Table 4.11). However, this relationship was not sufficiently strong to cause variation with sample site.

Principal components analysis of sediment data (Table 4.12) showed that percent moisture, organic content, iron content and manganese content were the main attributes contributing to a heterogeneous clustering of sampling sites with respect to proximity to tailings effluent. For example, as illustrated in Figure 4.4 (left side) Effluent Creek and Quirke Lake samples cluster together and Pow, Hidden and Collins Bays grouped together as would be expected. However, the same plot shows Serpent River/ Stollery Lake, Collins Creek, Esten Lake and Dunlop Lake samples grouped together. Another plot of sample sites show "creek samples" separating from the rest due to lower organic content in creek sediments (Figure 4.4, right plot). Two other plots of sample sites show heterogeneous clusters forming according to U and iron content or Ra and manganese content (Figure 4.5, left and right plots respectively). The Serpent River at Stollery Lake formed a distinct cluster according to Ra-226 levels along component 4 (Table 4.12, plot not shown). Collins Bay, Pow Bay and Effluent Creek formed a cluster on the negative end of component 4; all other sites clustered together.

Plots of samples by "sediment type" did not add any information regarding parameters affecting radionuclide levels or K_d's (Figure 4.6). The plots of sediment type produced clusters similar to those of sample site (Figure 4.4). The general mix of

sediment types within clusters reflects the difficulties inherent in qualitatively categorizing sediments in the field.

The large stream riffle habitat was the only habitat type that consistently clustered on the PCA plots. This habitat was distinguished by low organic content and low K_d's (Figure 4.7).

Sample site over-rode effects of habitat. Plots of habitat types are identical to those of sample site as seen on comparison of Figure 4.4 to 4.7 and Figure 4.5 to 4.8.

In summary, the above analyses indicate that U levels in sediments in this study were related to sample site location, organic content, iron content and manganese content. Ra-226 levels were related to iron content, manganese content, and to a lesser extent than U, proximity to tailings areas. Neither U nor Ra-226 K_d's showed strong and/or consistent relationships with the parameters tested in this study.

4.3 Invertebrates

Uranium levels in invertebrates were consistently higher downstream of uranium mine facility discharges. In Ontario, U levels were elevated in all samples from the Serpent River/ Stollery Lake site, Quirke Lake site, and the Pecors Lake site (Table 4.13). In Saskatchewan, U levels were elevated in all Rabbit Creek samples, Hidden Bay midges and all Effluent Creek samples (Table 4.14).

Radium-226 did not show as great a tendency to increase in invertebrates downstream of tailings area discharges. In Ontario, Ra-226 levels did not increase dramatically downstream of Dunlop Lake with two exceptions; caddisflies in Pecors Lake and blackflies in the Serpent River downstream of Stollery Lake

(Table 4.13). In Saskatchewan, Ra-226 levels were elevated in all Rabbit Creek samples, but not in any Hidden Bay or Effluent Creek samples (Table 4.14).

Variability of U and Ra-226 levels in invertebrate samples where replicates were possible is quite low (Table 4.15). This low variability is interesting, given the number of factors that can contribute to sample variation, e.g. particles adhering to the exoskeleton and the fullness of the gut.

Sediment-invertebrate bioaccumulation factors (BF's) are very low compared with water-invertebrate BF's; most are less than 1.0 (Tables 4.16 and 4.17). The range between upper and lower extreme values is smaller for sediment-based BF's than for water-based BF's. There is a similar range of BF's between the two regions (Ontario and Saskatchewan). Both water and sediment-based BF's are normally distributed ($p<0.01$) according to the Kolomagorov D statistic (SAS 1982).

As a general observation, uranium BF's tend to be higher than Ra-226 BF's in invertebrates from sites close to effluent discharges. At control sites, the opposite relationship occurs; Ra-226 BF's are higher than U BF's (Tables 4.16 and 4.17). These observations are especially evident for the water-based BF's.

Water-based BF's do not appear to vary consistently with genus; sediment-based BF's do vary with genus. Midge larvae have consistently higher sediment-based BF's than other genera at the same location. Oligochaete (worm) and caddisfly sediment-based BF's are also higher than for other genera. Amphipods (water scuds) have very low sediment-based BF's.

The invertebrate ANOVA results showed significant variation with sample site (Table 4.18). Uranium and Ra-226 levels and BF's all

differed significantly among sample sites, with the exception of water-invertebrate U BF's.

The ANOVA confirmed that there was a relationship between invertebrate type and radionuclide accumulation. Unfortunately, "feeding groups" rather than genera had to be used in the ANOVA due to the lack of genera common to all sample sites. The ANOVA showed that the feeding groups differed significantly with respect to U levels and U and Ra-226 sediment-based BF's (Table 4.8). Water-based BF's did not differ with feeding group.

There was a significant interaction between sample site and feeding group results for U levels and U and Ra-226 sediment-based BF's. Thus, the differences among sites depended in part on the feeding groups sampled there, and vice versa.

The S-N-K test showed that proximity to tailings area effluent was a factor affecting U or Ra-226 levels and BF's in invertebrates. The Serpent River/Stollery Lake and Rabbit Creek sites were most frequently shown to be significantly different from the other sites. These two sites are close to effluent discharges and had significantly elevated Ra-226 and U levels and sediment-based BF's (Tables 4.19 and 4.20). Effluent Creek, Quirke Lake, Pecors Lake, Serpent River at Pecors and Esten Lake invertebrates had significantly higher U levels (Table 4.19). Esten Lake littoral (nearshore) invertebrates had the highest Ra-226 water-based BF's (Table 4.21).

The S-N-K test also showed that proximity to effluent discharges was not the only factor affecting BF's. This was illustrated by Effluent Creek, Pecors Lake (main site) and Serpent River downstream of Pecors Lake invertebrates having significantly lower Ra-226 water-based BF's than invertebrates at other sites that were further away from effluent discharges (Table 4.21). In

addition, Ra-226 water based BF's differed at sites within Pecors Lake (Table 4.21). Therefore, other factors, such as species at the site, affect BF's as discussed below.

The S-N-K test showed that filter-feeders and omnivores had the greatest tendency to differ significantly from other groups. Filter-feeders (eg. blackflies) had significantly higher Ra-226 and U levels and Ra-226 water-based BF's, and significantly lower U sediment based BF's (Tables 4.22 to 4.24). Omnivores (e.g. some caddisfly genera) had signficiantly higher U levels, Ra-226 and U sediment-based BF's, and signficantly lower Ra-226 water-based BF's (Tables 4.22 to 4.24).

The largest number of significant differences among feeding groups occurred with respect to sediment-based U BF's and water-based Ra-226 BF's. All five feeding groups had significantly different U sediment-based BF's at most locations (Table 4.24). Radium-226 water-based BF's separated the feeding groups as follows, in order of decreasing BF's: filter feeders/herbivores, predators, detritivores/omnivores (Table 4.23).

The results of principal components analysis of invertebrate data are shown on Table 4.25. The plot of PRIN1 versus PRIN2 on Figure 4.9 (top) indicates that proximity to tailings area effluent was an important factor influencing radionuclide levels and BF's in invertebrates. Rabbit Creek samples clustered due to high U levels and Ra-226 and U sediment-based BF's. The Serpent River at Stollery Lake samples clustered due to high U and Ra-226 levels and Ra-226 water-based BF's. Effluent Creek samples were distinguished by high uranium levels and low Ra-226 and U sediment-based BF's (Figures 4.12 and 4.13.) These three sites are the closest to effluent discharges. None of the other sample sites clustered consistently.

Filter feeders formed the most consistent clusters in the principal components analysis. They clustered according to Ra-226 levels and water-based Ra-226 BF's (Figure 4.10, bottom). They clustered according to U levels and both U and Ra-226 sediment-based BF's in Figures 4.11 to 4.13.

Some omnivores clustered according to low sediment-based Ra-226 BF's and U BF's (Figures 4.12 and 4.13, top). However, other omnivores frequently clustered with some detritivores or within completely heterogeneous groupings (Figures 4.10 to 4.13.).

The other feeding group clusters appeared to depend more on sample site than on feeding style. The interaction between sample site and feeding group is illustrated by the identical clusters for these two categories on the plots (Figure 4.9/top and 4.10/bottom, Figure 4.12, Figure 4.13).

Sample site also over-rode sediment type and habitat differences in the invertebrate plots (Figures 4.9 and 4.10).

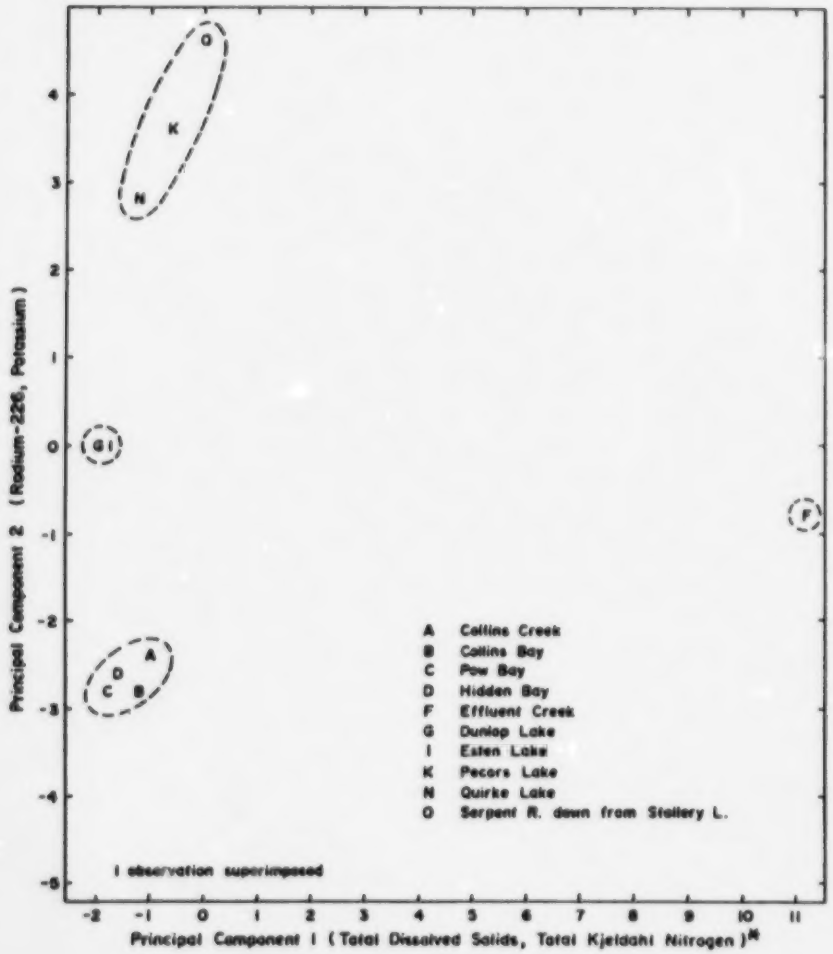
In summary, the above analyses showed that in this study, proximity to tailings area effluent affected U and Ra-226 levels and BF's in invertebrates; however the effect was not always an increase. The feeding group of the invertebrate also influenced the U and Ra-226 BF's; the effects were most pronounced in sediment-based U BF's and water-based Ra-226 BF's.

4.4 Fish Stomach Content Radionuclide Levels

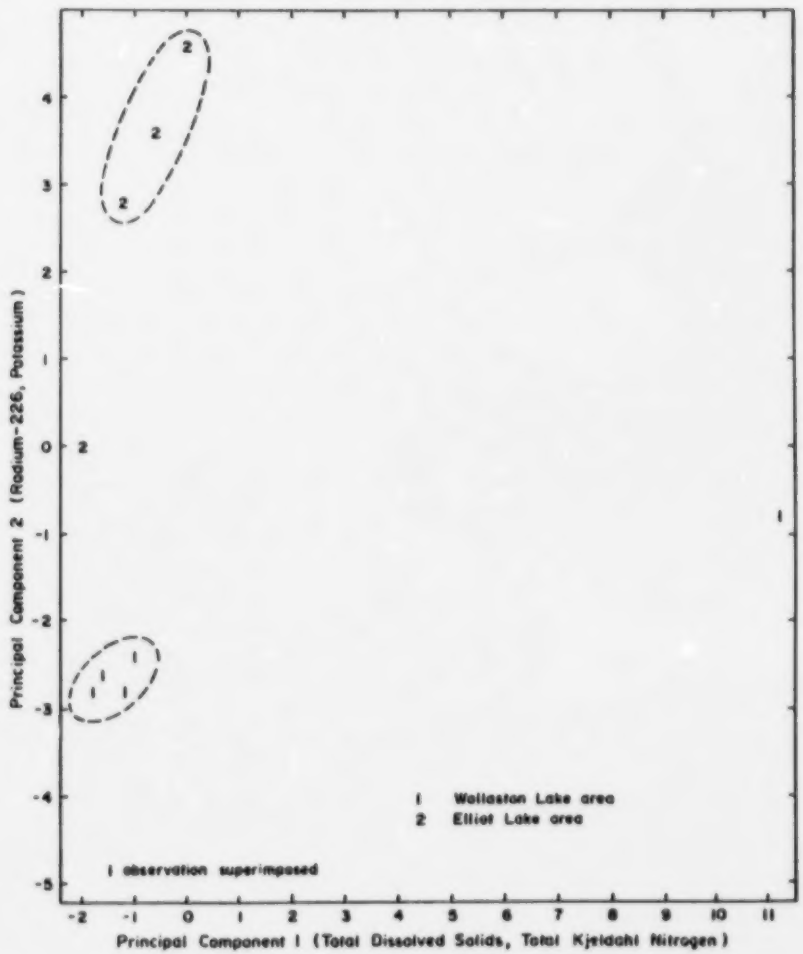
A small sample of the fish stomachs collected in Ontario and Saskatchewan was selected and the contents identified and analysed for Ra-226 and U (Tables 4.26 and 4.27). These data show radionuclide levels in the actual mixture of food items that a fish consumes.

In general, the radionuclide levels in the fish stomach contents were greater than levels found in invertebrate samples. Midge larvae, clams, snails, water scuds, fish and detritus were the most common food items (Table 4.26).

Radionuclide levels differed with fish species (Table 4.27). Suckers had the highest levels, particularly in lakes near tailings effluent discharges (e.g. Quirke Lake, Hidden Bay). Lake whitefish had elevated U levels relative to Ra-226 levels. Brook trout from Quirke Lake (feeding largely on beetles) had Ra-226 and uranium levels similar to those in whitefish. The predatory northern pike had the lowest levels.



* other highly correlated attributes on this component are either part of total dissolved solids, or are consistently below detection limits.


Principal Component 2 (Radium-226, Potassium)
Principal Component 1 (Total Dissolved Solids, Total Kjeldahl Nitrogen)
1 Wollaston Lake area
2 Elliot Lake area
1 observation superimposed

NOTE: ATTRIBUTES THAT ARE HIGHLY CORRELATED WITH EACH PC ARE IN PARENTHESES

Figure 4.1 WATER PCA PLOTS BY SAMPLE SITE AND REGION

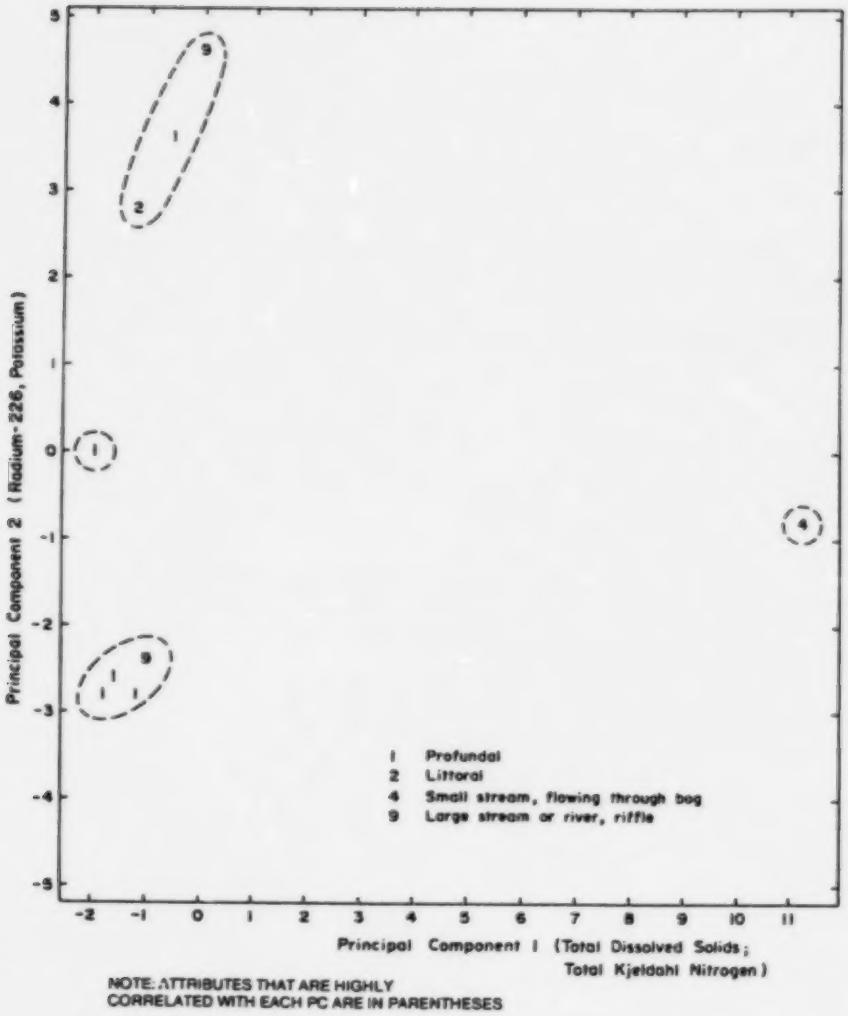

Principal Component 2 (Radium-226, Potassium)
Principal Component 1 (Total Dissolved Solids; Total Kjeldahl Nitrogen)
1 Profundal
2 Littoral
4 Small stream, flowing through bog
9 Large stream or river, riffle
NOTE: ATTRIBUTES THAT ARE HIGHLY CORRELATED WITH EACH PC ARE IN PARENTHESES

Figure 4.2 **WATER PCA PLOTS BY HABITAT TYPE**

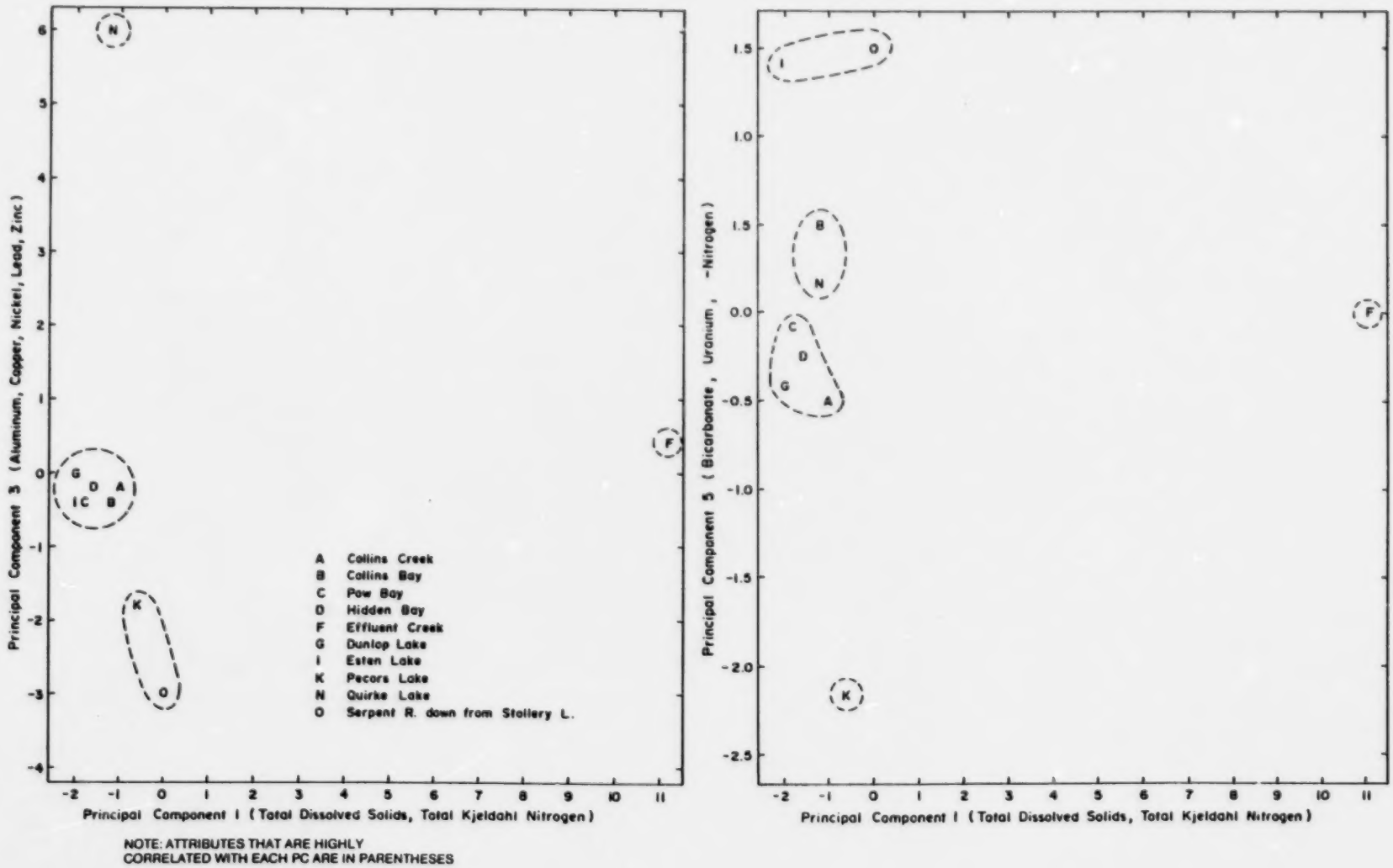
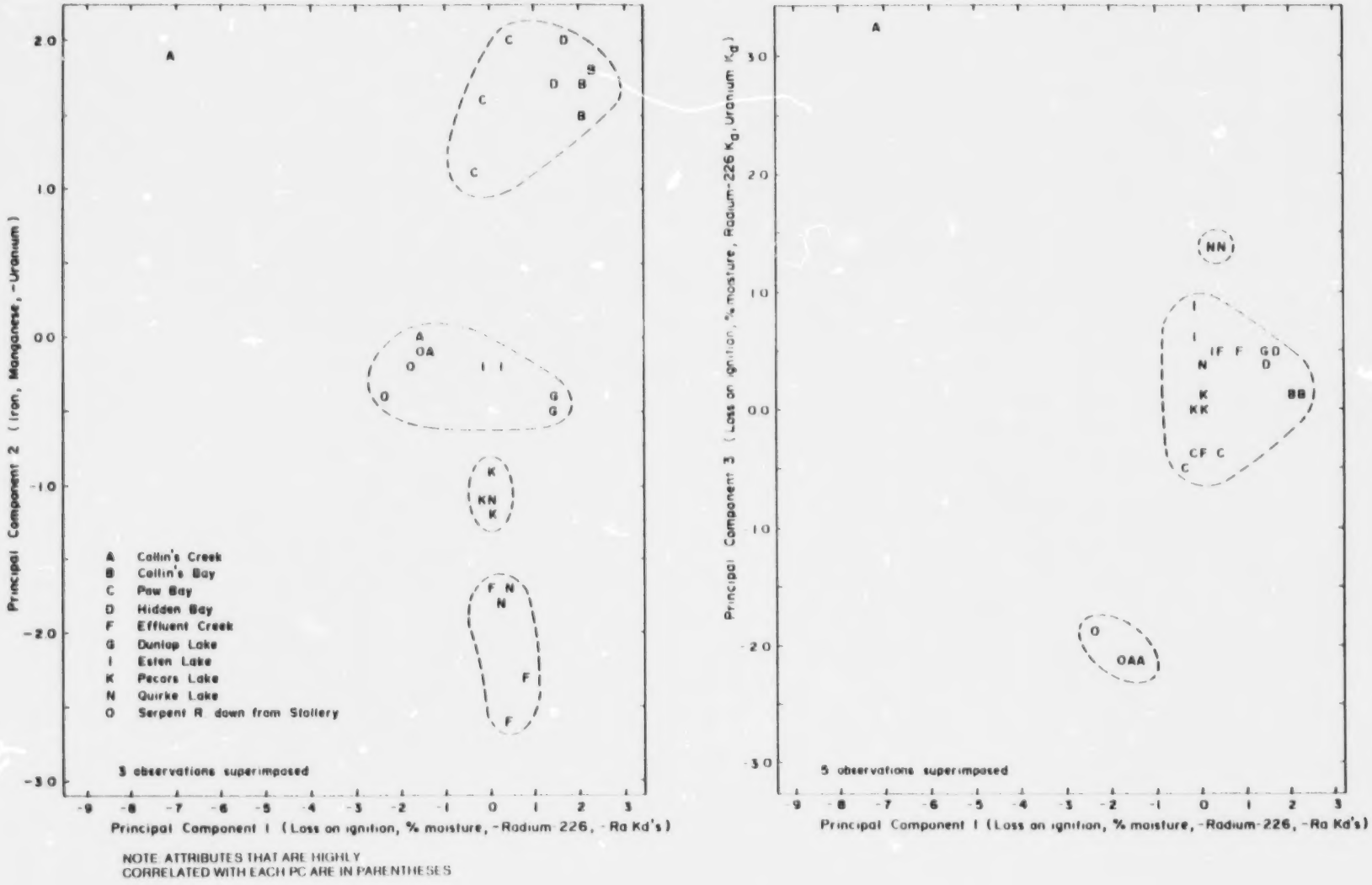

Principal Component 3 (Aluminum, Copper, Nickel, Lead, Zinc)
Principal Component 1 (Total Dissolved Solids, Total Kjeldahl Nitrogen)
A Collins Creek
B Collins Bay
C Pow Bay
D Hidden Bay
F Effluent Creek
G Dunlop Lake
I Esten Lake
K Pecors Lake
N Quirke Lake
O Serpent R. down from Stollery L.
NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES
Principal Component 5 (Bicarbonate, Uranium, -Nitrogen)
Principal Component 1 (Total Dissolved Solids, Total Kjeldahl Nitrogen)

Figure 4.3 **WATER PCA PLOTS BY SAMPLE SITE**


Principal Component 2 (Iron, Manganese, -Uranium)
Principal Component 1 (Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
A Collin's Creek
B Collin's Bay
C Paw Bay
D Hidden Bay
F Effluent Creek
G Dunlop Lake
I Esten Lake
K Pecors Lake
N Quirke Lake
O Serpent R. down from Stollery
3 observations superimposed
Principal Component 3 (Loss on ignition, % moisture, Radium-226 Kg, Uranium Kg)
Principal Component 1 (Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
5 observations superimposed

NOTE ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

Figure 4.4 **SEDIMENT PCA PLOTS BY SAMPLE SITE**

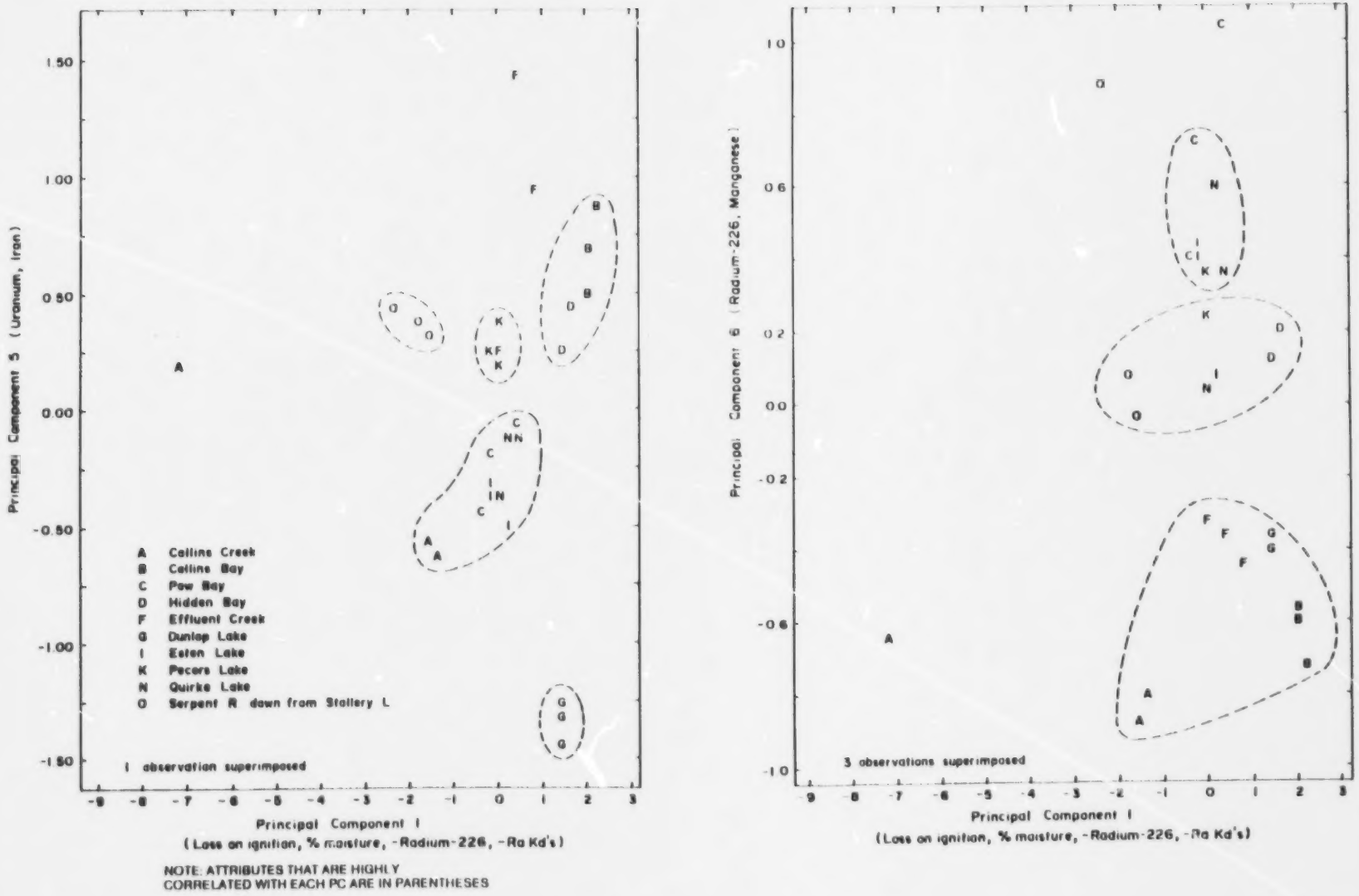
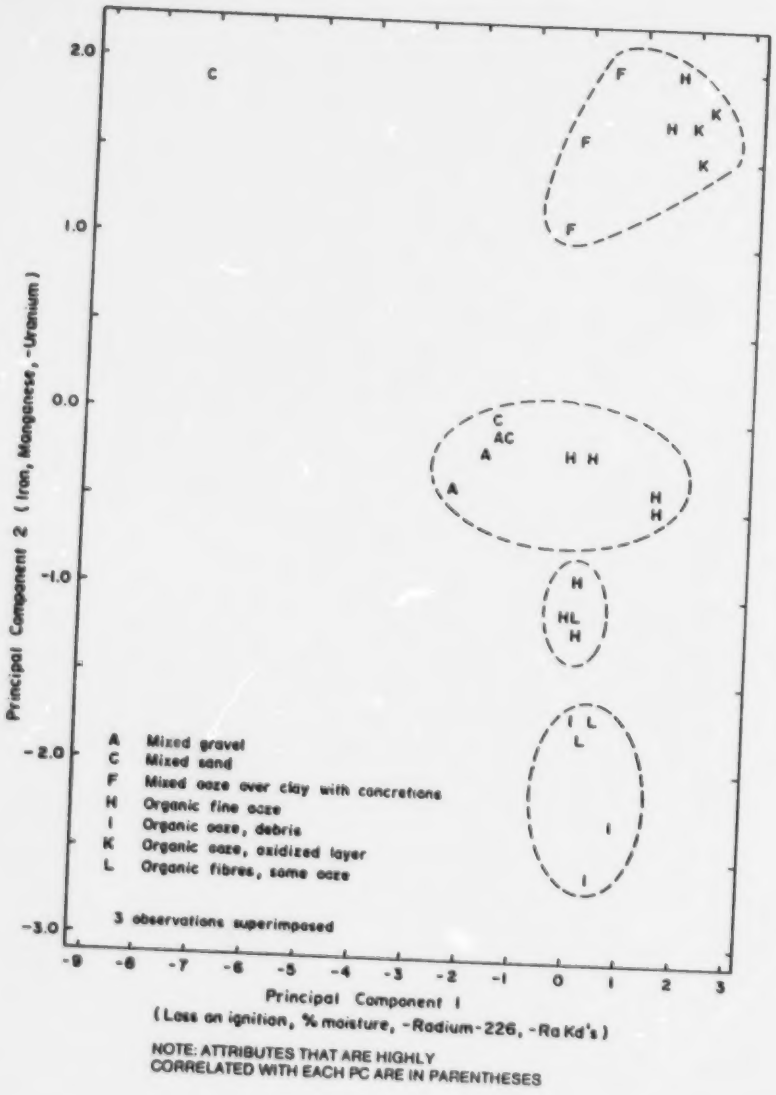

Principal Component 5 (Uranium, Iron)
Principal Component 6 (Radium-226, Manganese)
A Collins Creek
B Collins Bay
C Pow Bay
D Hidden Bay
F Effluent Creek
G Dunlop Lake
I Esten Lake
K Pecors Lake
N Quirke Lake
O Serpent R down from Stollery L
1 observation superimposed
3 observations superimposed
Principal Component 1
(Loss on ignition, % moisture, - Radium-226, - Ra Kd's)
NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

Figure 4.5 SEDIMENT PCA PLOTS BY SAMPLE SITE


Principal Component 2 (Iron, Manganese, -Uranium)
Principal Component 1
(Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
A Mixed gravel
C Mixed sand
F Mixed ooze over clay with concretions
H Organic fine ooze
I Organic ooze, debris
K Organic ooze, oxidized layer
L Organic fibres, some ooze
3 observations superimposed
NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

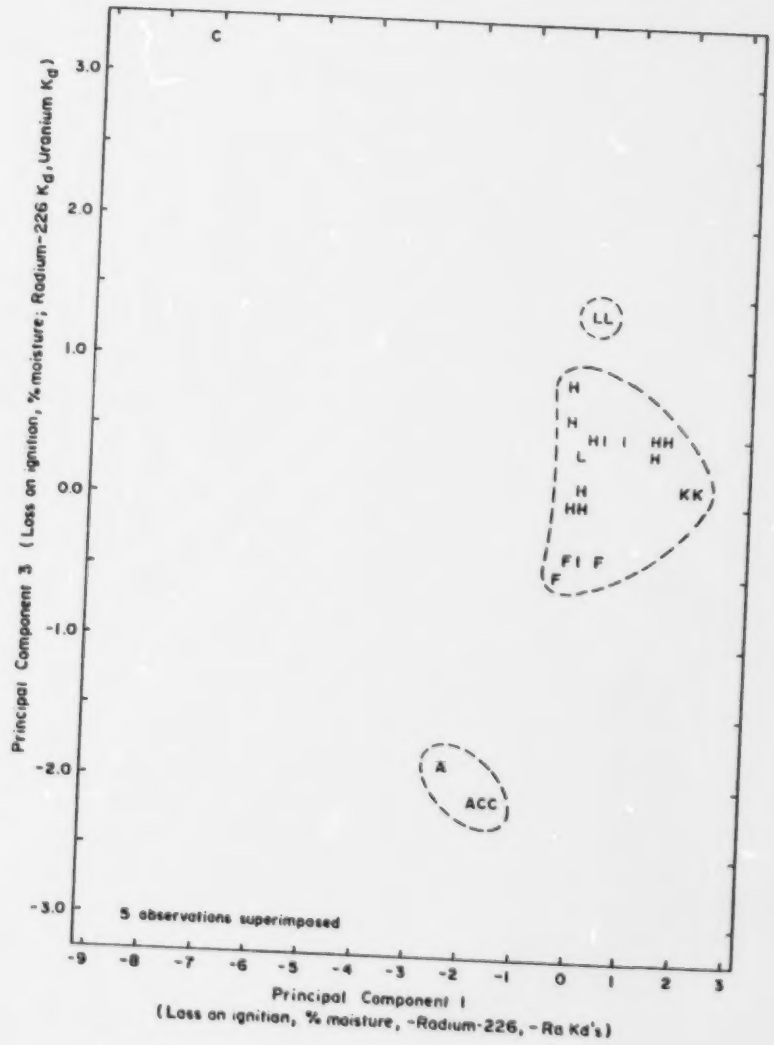
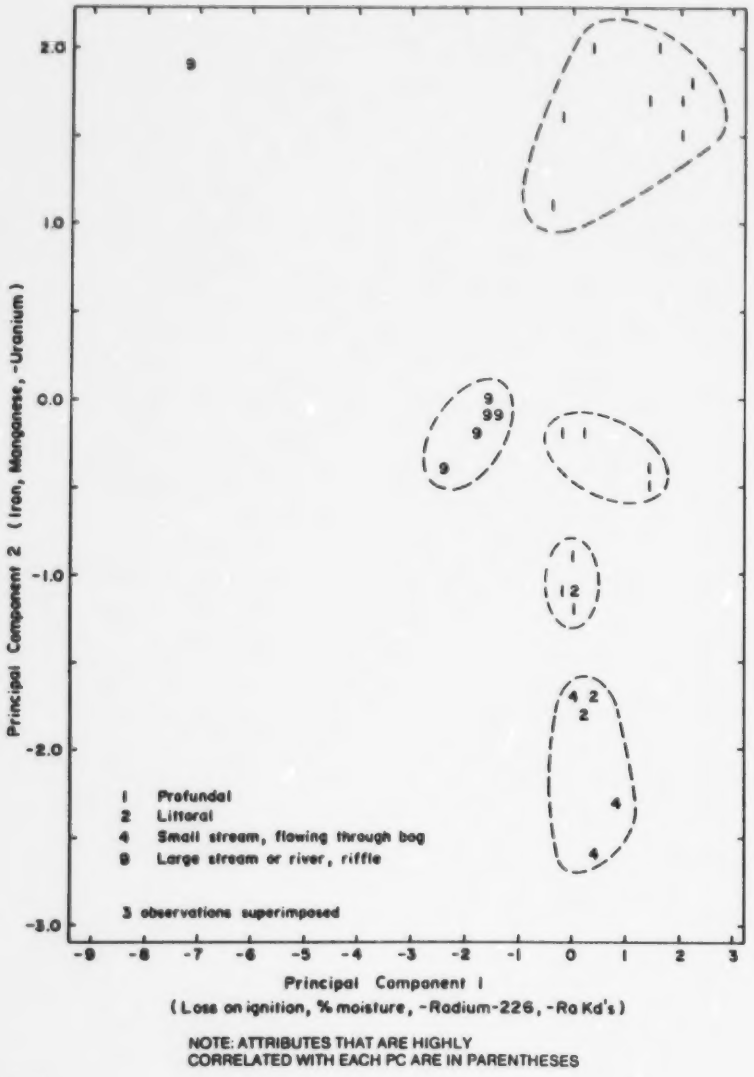

Principal Component 3 (Loss on ignition, % moisture; Radium-226 K_d, Uranium K_d)
Principal Component 1
(Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
5 observations superimposed

Figure 4.6 **SEDIMENT PCA PLOTS BY SEDIMENT TYPE**


Principal Component 2 (Iron, Manganese, -Uranium)
Principal Component 1
(Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
1 Profundal
2 Littoral
4 Small stream, flowing through bog
9 Large stream or river, riffle
3 observations superimposed
NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

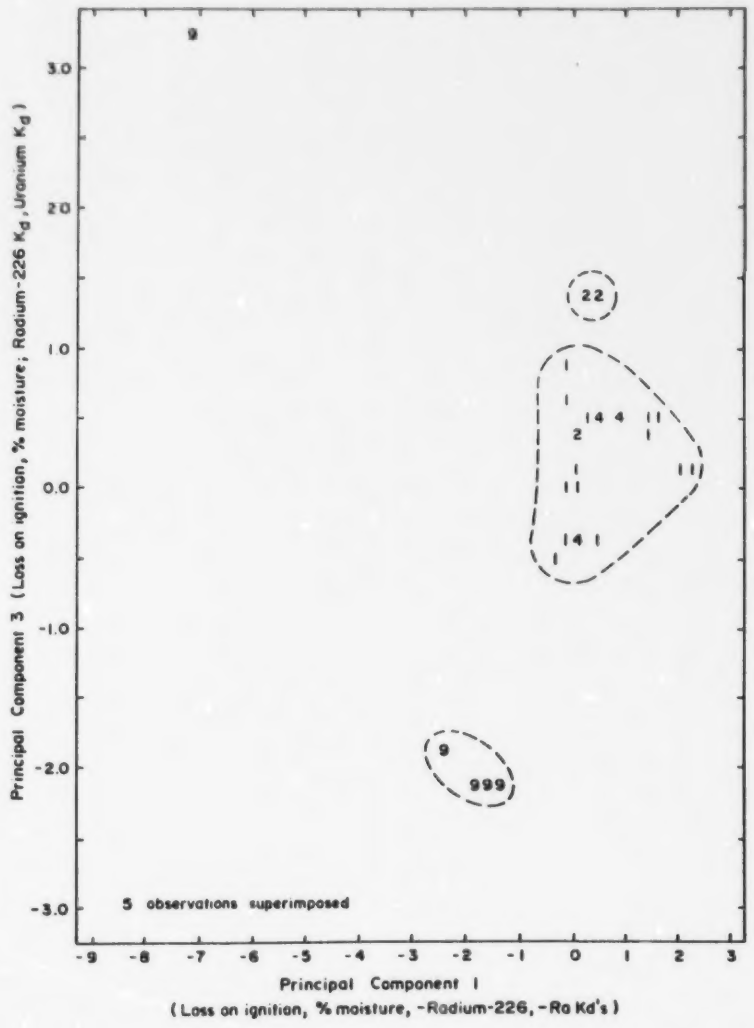
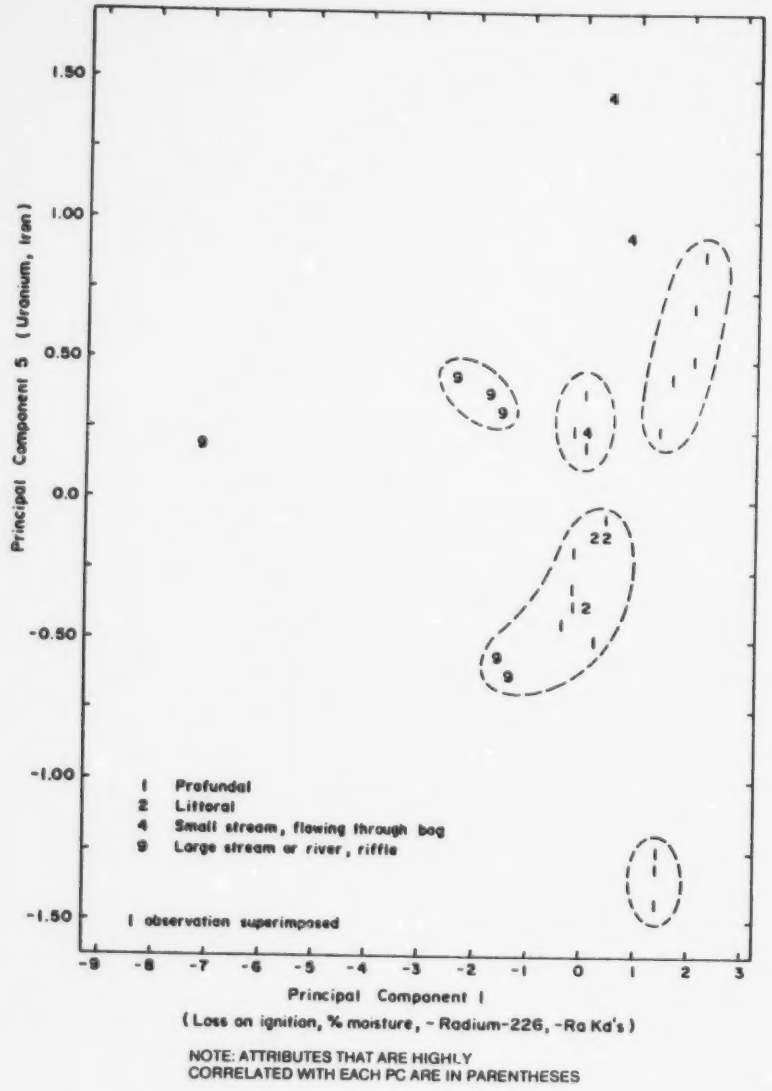

Principal Component 3 (Loss on ignition, % moisture; Radium-226 K_d, Uranium K_d)
Principal Component 1
(Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
5 observations superimposed

Figure 4.7 SEDIMENT PCA PLOTS BY HABITAT TYPE


Principal Component 5 (Uranium, Iron)
Principal Component 1
(Loss on ignition, % moisture, - Radium-226, -Ra Kd's)
1 Profundal
2 Littoral
4 Small stream, flowing through bog
9 Large stream or river, riffle
1 observation superimposed
NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

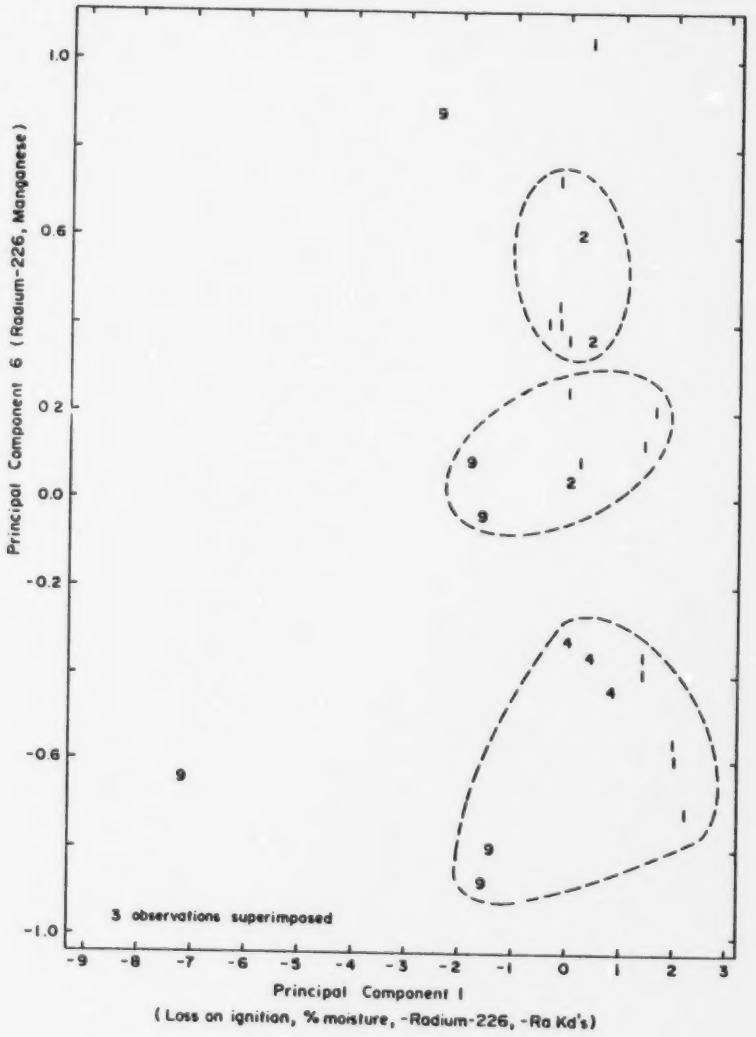
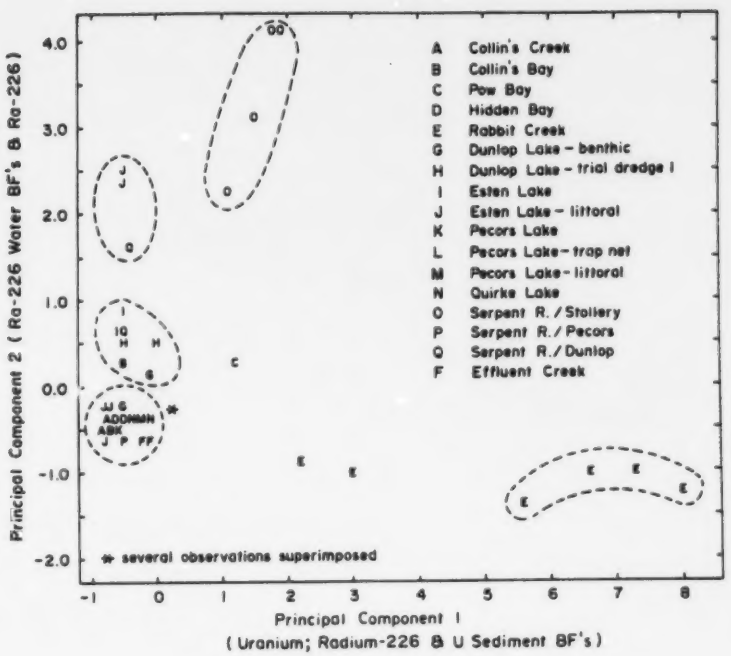

Principal Component 6 (Radium-226, Manganese)
Principal Component 1
(Loss on ignition, % moisture, -Radium-226, -Ra Kd's)
3 observations superimposed

Figure 4.8 **SEDIMENT PCA PLOTS BY HABITAT TYPE**


A Collin's Creek
B Collin's Bay
C Pow Bay
D Hidden Bay
E Rabbit Creek
G Dunlop Lake – benthic
H Dunlop Lake – trial dredge I
I Esten Lake
J Esten Lake – littoral
K Pecors Lake
L Pecors Lake – trap net
M Pecors Lake – littoral
N Quirke Lake
O Serpent R. / Stollery
P Serpent R. / Pecors
Q Serpent R. / Dunlop
F Effluent Creek
* several observations superimposed
Principal Component 2 (Ra-226 Water BF's & Ra-226)
Principal Component 1
(Uranium; Radium-226 & U Sediment BF's)

NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

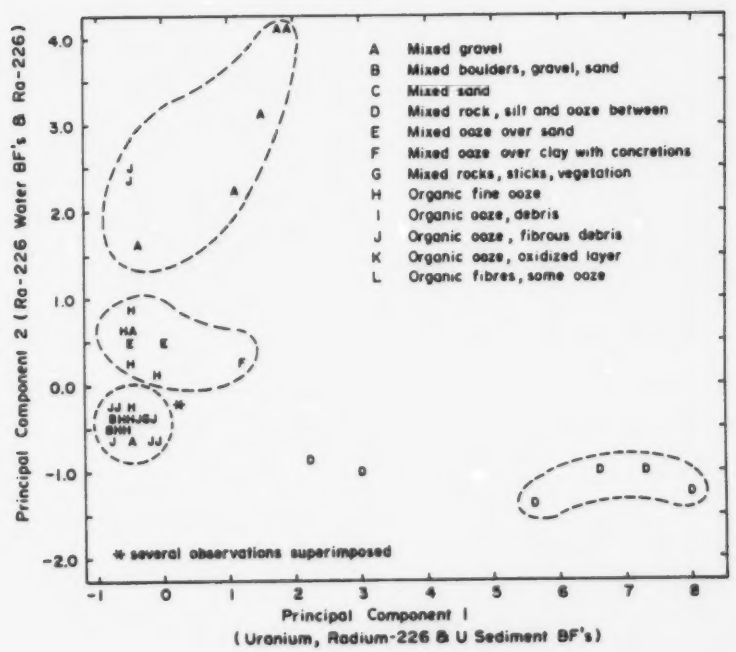
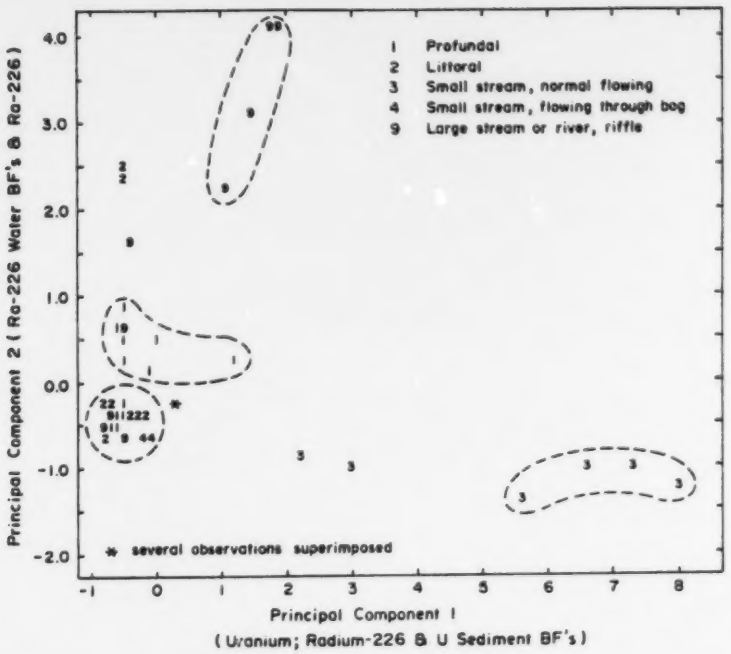

A Mixed gravel
B Mixed boulders, gravel, sand
C Mixed sand
D Mixed rock, silt and ooze between
E Mixed ooze over sand
F Mixed ooze over clay with concretions
G Mixed rocks, sticks, vegetation
H Organic fine ooze
I Organic ooze, debris
J Organic ooze, fibrous debris
K Organic ooze, oxidized layer
L Organic fibres, some ooze
* several observations superimposed
Principal Component 2 (Ra-226 Water BF's & Ra-226)
Principal Component 1
(Uranium, Radium-226 & U Sediment BF's)

Figure 4.9 **INVERTEBRATE PCA PLOTS BY SAMPLE SITE AND SEDIMENT TYPE**


1 Profundal
2 Littoral
3 Small stream, normal flowing
4 Small stream, flowing through bog
9 Large stream or river, riffle
* several observations superimposed
Principal Component 2 (Ra-226 Water BF's & Ra-226)
Principal Component 1
(Uranium; Radium-226 & U Sediment BF's)

NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

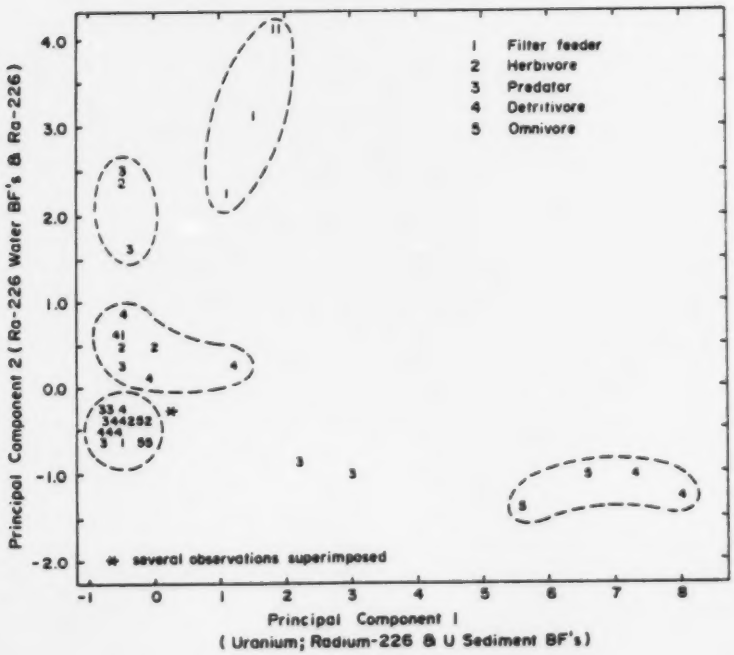

1 Filter feeder
2 Herbivore
3 Predator
4 Detritivore
5 Omnivore
* several observations superimposed
Principal Component 2 (Ra-226 Water BF's & Ra-226)
Principal Component 1
(Uranium; Radium-226 & U Sediment BF's)

Figure 4.10 INVERTEBRATE PCA PLOTS BY HABITAT TYPE AND FEEDING GROUP

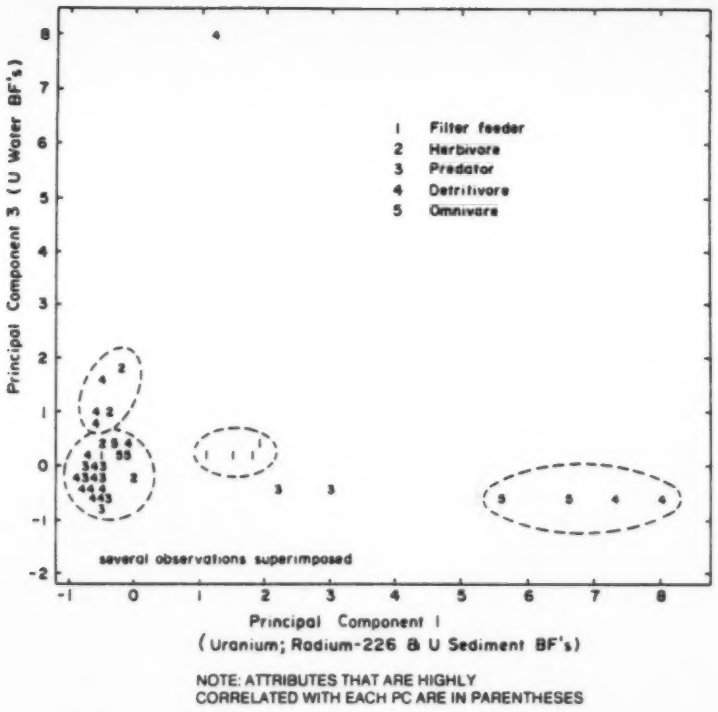
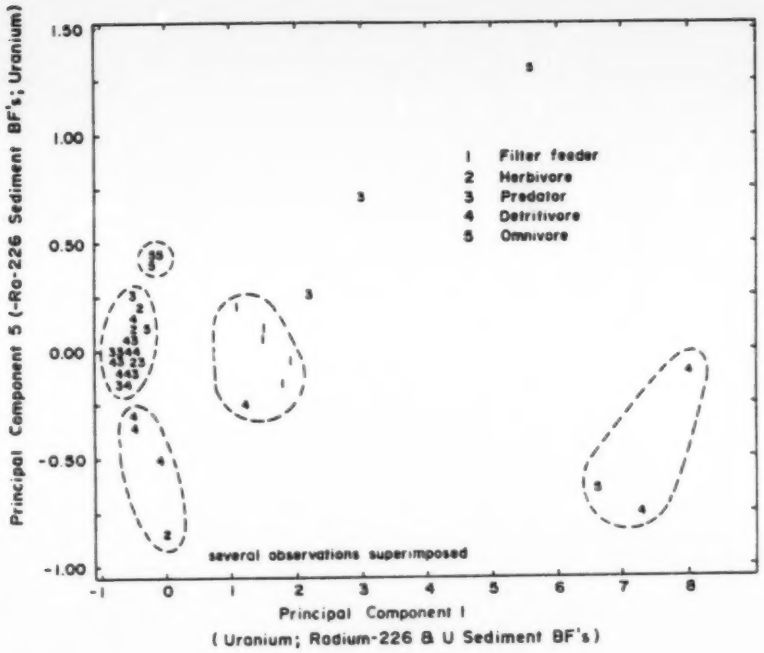


Figure 4.11 **INVERTEBRATE PCA PLOTS BY FEEDING GROUP**



NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES

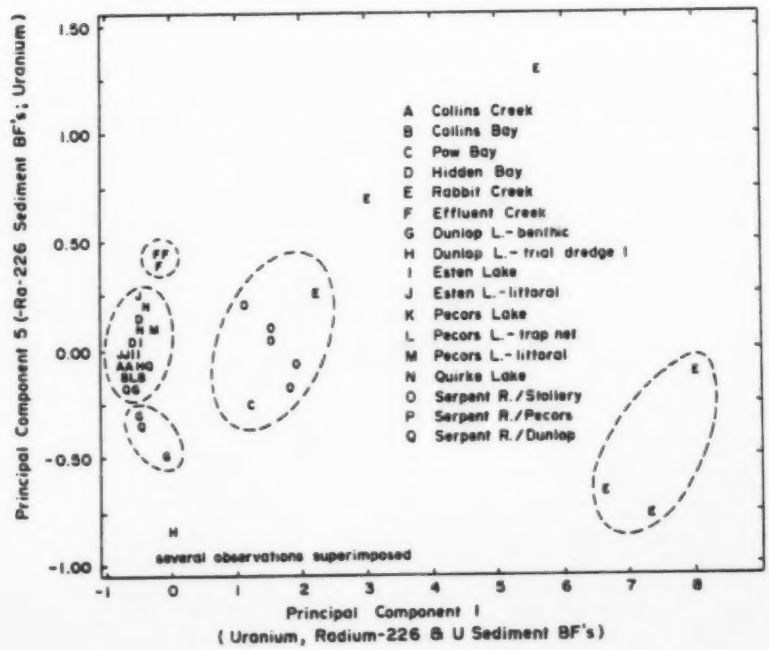


Figure 4.12 **INVERTEBRATE PCA PLOTS BY SAMPLE SITE AND FEEDING GROUP**

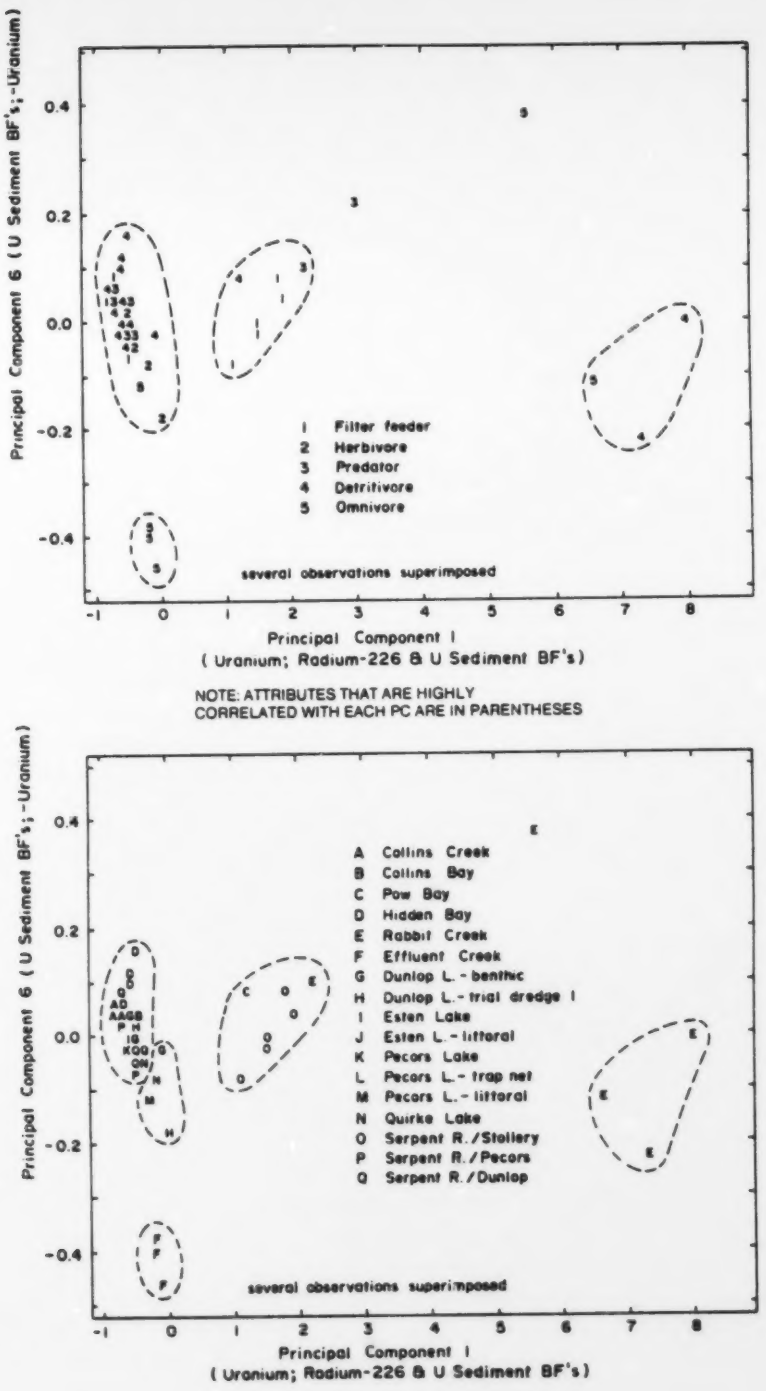

Principal Component 6 (U Sediment BF's; -Uranium)
Principal Component 1
(Uranium; Radium-226 & U Sediment BF's)
1 Filter feeder
2 Herbivore
3 Predator
4 Detritivore
5 Omnivore
several observations superimposed
NOTE: ATTRIBUTES THAT ARE HIGHLY
CORRELATED WITH EACH PC ARE IN PARENTHESES
A Collins Creek
B Collins Bay
C Pow Bay
D Hidden Bay
E Rabbit Creek
F Effluent Creek
G Dunlop L. - benthic
H Dunlop L. - trial dredge 1
I Esten Lake
J Esten L. - littoral
K Pecors Lake
L Pecors L. - trap net
M Pecors L. - littoral
N Quirke Lake
O Serpent R. / Stollery
P Serpent R. / Pecors
Q Serpent R. / Dunlop

Figure 4.13 **INVERTEBRATE PCA PLOTS BY SAMPLE SITE AND FEEDING GROUP**

Table 4.1

WATER ANALYSIS RESULTS; ONTARIO; ALL LAKE SAMPLES FROM 0.5 m ABOVE BOTTOM

	Units	Dunlop Lake	Esten Lake	Pecors Lake	Quirke Lake	Serpent River downstream of Stollery Lake
FIELD MEASUREMENTS						
pH		6.5	6.7	6.3	6.5	6.6
Conductivity	umhos	29	80	223	45	304
alkalinity as	mg/L $CaCO_3$	3.0	11.0	2.5	3.5	6.0
thermal stratification	-	no	yes	no	n/a*	-
dissolved oxygen	mg/L	11.3	10.2	10.3	10.2	10.8
MAJOR CONSTITUENTS						
CO_3, acid titr.	mg/L	nil	nil	nil	nil	nil
Ca as Ca	mg/L	8	9	49	15	52
Cl, $AgNO_3$ titr.	mg/L	2	12	12	2	19
HCO_3, acid titr.	mg/L	<0.1	14	3	6	8
K, flame	mg/L	<0.2	0.5	8.6	2.5	11
Mg as Mg	mg/L	<1	2	1	<1	1
Na, flame	mg/L	0.7	7.2	5.9	2.1	10
OH	mg/L	nil	nil	nil	nil	nil
SO_4, gravi.	mg/L	6.3	17	112	29	127
NUTRIENTS						
C, tot. org.	mg/L	<1	<1	<1	<1	<1
N, Ammonia	mg/L	<0.01	0.01	0.01	0.39	0.05
N, NO_2 + NO_3	mg/L	0.04	0.02	6.0	1.5	1.0
N, total Kjeld.	mg/L	0.19	0.50	1.8	0.56	4.6
P, inorganic	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02
P, total as P	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02
PO_4, ortho as P	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02
TRACE METALS						
Ag, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Al, ICP-AES	mg/L	0.01	0.02	0.10	1.2 **	0.08
Ba, ICP-AES	mg/L	0.020	0.020	0.026	0.024	0.042
Bi, by A.A.	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Cd, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Co, ICP-AES	mg/L	<0.001	<0.001	0.001	<0.001	<0.001
Cr, ICP-AES	mg/L	0.002	0.002	0.001	0.005	0.001
Cu, ICP-AES	mg/L	0.002	0.002	0.002	0.25**	0.002
Fe, ICP-AES	mg/L	0.023	0.036	0.030	0.25	0.049
Mn, ICP-AES	mg/L	0.008	0.023	0.19	0.057	0.033
Mo, ICP-AES	mg/L	<0.005	<0.005	<0.005	<0.005	0.005
Ni, ICP-AES	mg/L	0.003	0.002	0.005	0.082	0.002
Pb, ICP-AES	mg/L	<0.005	<0.005	<0.005	0.60**	<0.005
Si, By A.A.	mg/L	0.34	0.31	1.0	0.94	1.1
Sn, by A.A.	mg/L	<1	<1	<1	<1	<1
Ti, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
V, ICP-AES	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
W, ICP-AES	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Zn, ICP-AES	mg/L	0.010	0.010	0.026	6.1**	0.011

Table 4.1 cont'd

		Dunlop Lake	Esten Lake	Pecors Lake	Quirke Lake	Serpent River downstream of Stollery Lake
PHYSICAL PROPERTIES						
Solids, Total Dissolved	mg/L	56	102	271	121	318
RADIONUCLIDES						
Ra-226, diss.	Bq/L	<0.005	<0.005	0.12	0.03	0.15
Ra-226, diss.	Bq/L	<0.005	<0.005	0.10	0.02	0.13
Ra-226, diss.	Bq/L	<0.005	<0.005	0.10	0.02	0.13
Ra-226, total	Bq/L	<0.005	<0.005	0.12	0.03	0.17
Ra-226, total	Bq/L	<0.005	0.005	0.11	0.02	0.16
Ra-226, total	Bq/L	<0.005	0.005	0.11	0.02	0.17
U, diss.	ug/L	<0.5	<0.5	4.4±0.3	1.9±0.3	16±1
U, diss.	ug/L	<0.5	0.6±0.2	6.3±0.3	2.5±0.3	17±2
U, diss.	ug/L	<0.5	<0.5	5.2±0.2	2.5±0.2	19±2
U, total	ug/L	<0.5	<0.5	5.2±0.3	2.3±0.3	17±1
U, total	ug/L	0.5± 0.2	0.8±0.3	6.7±0.3	2.7±0.3	21±2
U, total	ug/L	<0.5	0.5±0.3	6.2±0.4	2.5±0.2	20±2

* Information not available
** Levels of Al, Cu, Pb, Zn indicate some metal contamination of sample may have occurred.

Table 4.2

WATER ANALYSIS RESULTS; SASKATCHEWAN; LAKE SAMPLES FROM 0.5 m ABOVE BOTTOM

		Collins Creek	Collins Bay	Pow Bay	Hidden Bay	Effluent Creek
FIELD MEASUREMENTS						
pH		7.3	7.4	7.3	7.4	6.6
Conductivity	umhos	80	30	60	78	2325
alkalinity as	mg/L $CaCO_3$	0.6	0.9	0.9	0.9	0.4
thermal stratification		-	yes	no	no	-
dissolved oxygen	mg/L	8.8	13.0	12.8	11.5	8.5
MAJOR CONSTITUENTS						
CO_3, acid titr.	mg/L	nil	nil	nil	nil	nil
Ca as Ca	mg/L	1.2	2.4	2.6	2.9	102
Cl, $AgNO_3$ titr.	mg/L	0.1	0.1	0.1	0.2	44
HCO_3, acid titr.	mg/L	8	11	11	10	<1
K, flame	mg/L	<0.2	<0.2	<0.2	<0.2	5.5
Mg as Mg	mg/L	0.47	1.1	1.3	2.2	270
Na, flame	mg/L	1.0	1.0	1.1	1.1	19
OH	mg/L	nil	nil	nil	nil	nil
SO_4, gravi.	mg/L	1.3	3.7	4.4	8.0	1490
NUTRIENTS						
C, tot. org.	mg/L	4	4	2	2	4
C, total	mg/L	4	4	2	2	4
N, Ammonia	mg/L	0.02	0.02	0.02	0.13	54
N, NO_2 + NO_3	mg/L	0.01	0.007	0.02	0.03	1.4
N, total Kjeld.	mg/L	0.12	0.02	0.09	0.22	68
P, inorganic	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
P, total as P	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
PO_4, ortho as P	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
TRACE METALS						
Ag, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Al, ICP-AES	mg/L	0.03	0.03	0.02	0.08	0.12
As, hydride gen.	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5
Ba, ICP-AES	mg/L	0.036	0.041	0.008	0.008	0.015
Bi, by A.A.	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Cd, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Co, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	0.013
Cr, ICP-AES	mg/L	0.003	0.004	0.001	0.002	0.011
Cu, ICP-AES	mg/L	0.002	0.003	0.003	0.002	0.002
Fe, ICP-AES	mg/L	0.23	0.091	0.028	0.064	0.58
Mn, ICP-AES	mg/L	0.059	0.068	0.005	0.027	0.73
Mo, ICP-AES	mg/L	0.024	0.047	<0.005	<0.005	0.22
Ni, ICP-AES	mg/L	0.006	0.005	0.003	0.004	0.046
Pb, ICP-AES	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Si, By A.A.	mg/L	1.2	0.4	0.4	0.5	0.7

Table 4.2 cont'd

		Collins Creek	Collins Bay	Pow Bay	Hidden Bay	Effluent Creek
Sn, by A.A.	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Ti, ICP-AES	mg/L	<0.001	<0.001	<0.001	<0.001	0.002
V, ICP-AES	mg/L	<0.01	<0.01	<0.01	<0.01	0.05
W, ICP-AES	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Zn, ICP-AES	mg/L	<0.001	<0.001	<0.001	0.002	0.012
PHYSICAL PROPERTIES						
Solids, Total Dissolved	mg/L	41	32	28	54	2250
RADIONUCLIDES						
Ra-226, diss.	Bq/L	<0.005	<0.005	<0.005	<0.005	0.01
Ra-226, diss.	Bq/L	<0.005	<0.005	<0.005	<0.005	0.01
Ra-226, diss.	Bq/L	<0.005	<0.005	<0.005	<0.005	0.01
Ra-226, total	Bq/L	<0.005	<0.005	<0.005	<0.005	0.01
Ra-226, total	Bq/L	<0.005	<0.005	<0.005	<0.005	0.01
Ra-226, total	Bq/L	<0.005	<0.005	<0.005	<0.005	0.01
U, diss.	ug/L	<0.5	<0.5	<0.5	<0.5	12 ± 2
U, diss.	ug/L	<0.5	<0.5	<0.5	<0.5	12 ± 2
U, diss.	ug/L	<0.5	<0.5	<0.5	<0.5	13 ± 2
U, total	ug/L	<0.5	0.7 ± 0.2	<0.5	<0.5	17 ± 1
U, total	ug/L	<0.5	0.7 ± 0.2	<0.5	<0.5	17 ± 1
U, total	ug/L	<0.5	0.7 ± 0.2	<0.5	<0.5	17 ± 1

TABLE 4.3

WATER PRINCIPAL COMPONENTS ANALYSIS: SUMMARY

A. Eigenvalues (Latent Roots) of the Principal Components Extracted from the PCA Correlation Matrix

	Eigenvalue	Difference Between Successive Eigenvalues	Proportion of Variance Represented	Cumulative Proportion of Variance
PRIN1	15.7078	7.71061	0.461995	0.46199
PRIN2	7.9972	2.68491	0.235212	0.69721
PRIN3	5.3123	3.02942	0.156244	0.85345
PRIN4	2.2829	1.19915	0.067143	0.92059
PRIN5	1.0837	0.21675	0.031874	0.95247
PRIN6	0.8670	0.40117	0.025499	0.97797
PRIN7	0.4658	0.18930	0.013700	0.99167
PRIN8	0.2765	0.26973	0.008132	0.99980
PRIN9	0.0068	0.00677	0.000199	1.00000

B. Eigenvectors (Loadings) for Attributes in the Original Data Matrix on the First 6 Principal Components

	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5	PRIN6
Ca	0.221566[a,b]	0.153985	-.074287	-.013305	-.056649	-.068165
Cl	0.229143[a,b]	0.104352	-.079888	-.092909	0.138018	-.028913
HCO_3	-.121719	-.126796	-.045170	0.122075	0.514212[a]	-.355604
K	0.088075	0.288913[a,b]	-.158914	0.145383	-.041692	-.157631
Mg	0.249127[a,b]	-.032254	0.023910	-.077096	0.006401	0.000456
Na	0.220251[a,b]	0.115456	-.085074	-.076814	0.205971	-.069014
OH^-	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
SO_4	0.251133[a,b]	-.001037	0.006128	-.062469	-.002722	-.013524
Tot. Org C	0.124003	-.233730	-.020338	0.320868[a]	-.029543	0.286462
NH_3	0.249234[a,b]	-.031039	0.026672	-.074173	0.005257	0.002122
NO_2-NO_3	0.037597	0.222786	-.045583	0.017799	-.628301[a]	-.109288
TKN	0.250754[a]	-.013427	0.010993	-.063950	0.021278	-.006371
Inorg P	-.078407	0.296547[a,b]	0.033106	-.253969	0.078842	0.204378
Total P	-.078407	0.296547[a,b]	0.033106	-.253969	0.078842	0.204378
Ortho P	-.078407	0.296547[a,b]	0.033106	-.253969	0.078842	0.204378
Ag	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Al	-.010437	0.140459	0.386943[a]	0.112535	0.021963	-.122440
Ba	-.036608	0.119960	-.096654	0.409525[a]	0.221691	0.626493[a]
Bi	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cd	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Co	0.249241[a,b]	-.031724	0.024050	-.075005	0.004773	0.003951

Table 4.3 continued

	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5	PRIN6
Cr	0.221897[a,b]	-.052503	0.173054	0.025052	0.063124	0.178427
Cu	-.028938	0.125393	0.394535[a]	0.100640	0.048876	-.085145
Fe	0.222621[a,b]	-.031827	0.163786	0.121216	0.002497	0.121889
Mn	0.246885[a,b]	0.004547	0.011206	-.033003	-.150008	0.027996
Mo	0.245094[a,b]	-.065831	0.017026	-.003366	0.020908	0.113587
Ni	0.098157	0.095019	0.378145a	0.073075	0.016703	-.060064
Pb	-.028656	0.126265	0.394391[a]	0.099880	0.048382	-.084123
Si	0.034548	0.189230	0.004233	0.460787[a]	-.212059	0.071872
Sn	-.078407	0.296547[a,b]	0.033106	-.253969	0.078842	0.204378
Ti	0.249241[a,b]	-.031724	0.024050	-.075005	0.004773	0.003951
V	0.249241[a,b]	-.031724	0.024050	-.075005	0.004773	0.003951
W	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Zn	-.028431	0.127339	0.394058[a]	0.099061	0.046772	-.083871
TDS	0.250933[a]	0.016238	0.001528	-.060860	0.003402	-.017096
Dis. Ra-226	-.004404	0.295454[a]	-.193469	0.177782	-.054585	-.156734
Tot. Ra-226	-.004301	0.291256[a]	-.200741	0.185959	0.006268	-.155689
Diss. U	0.148692	0.214904	-.147830	0.146818	0.251226[a]	-.128848
Total U	0.172534	0.194320	-.134723	0.125859	0.230653[a]	-.115738

Notes:
a) Attributes with highest loadings; discussed in text.
b) Attributes that make up part of an overall attribute, or are artifacts (less than detection limits); are not specifically discussed.

Table 4.4

SEDIMENT ANALYSIS RESULTS

	Dunlop Lake		Esten Lake		Pecors Lake		Quirke Lake		Serpent River downstream of Stollery Lake	
	mean*	s.e.**	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
% L.O.I.	23.7	0.33	16	0.58	12.7	0.33	22.3	2.7	1.2	0
% Moisture	89	0	84	0	75.3	1.3	79	2.5	23.3	0.9
Fe mg/g dry	18.3	1.2	25.7	0.9	20.3	0.9	9.9	0.6	20.0	1.5
Mn mg/g dry	0.77	0.01	0.67	0.02	0.27	0.02	0.22	0.01	0.27	0.03
Ra-226 Bq/g dry	0.12	0.01	0.90	0.10	0.83	0.07	0.68	0.13	1.3	0.1
U ug/g dry	5.7	0.8	27.2	2.4	84.2	8.1	104.0	12.9	13.3	1.6

	Collins Creek		Collins Bay		Pow Bay		Hidden Bay		Effluent Creek	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
% L.O.I.	0.87	0.09	18	0	6.7	0.3	16.7	0.3	15.7	2.4
% Moisture	22.7	2.9	82.3	0.7	63.3	1.3	82	0	67.7	3.5
Fe mg/g dry	7.0	0.7	69.0	3.2	16.0	1.5	49.3	1.9	10.1	3.1
Mn mg/g dry	0.24	0.08	3.8	0.1	5.8	1.0	5.3	0.2	0.08	0.01
Ra-226 Bq/g dry	0.06	0.02	0.12	0.03	0.07	0.03	0.13	0.01	0.10	0.02
U ug/g dry	5.7	3.9	6.1	0.2	8.7	0.2	11.3	0.2	180.6	28.8

* mean = arithmetic mean
** s.e. = standard error

See Appendix I for details of analysis.

Table 4.5

WATER-SEDIMENT DISTRIBUTION COEFFICIENTS

Location		Ra-226 (mL/g (wet))	U (mL/g (wet))
Dunlop Lake	upper	3667	2182
	mean	3333	1909
	lower	3000	1636
Esten Lake	upper	53333	13000
	mean	35000	8269
	lower	24000	5765
Pecors Lake	upper	2200	4145
	mean	1818	3467
	lower	1500	2892
Quirke Lake	upper	8947	10294
	mean	7000	8720
	lower	5714	7290
Serpent River downstream of Stollery Lake	upper	8500	616
	mean	5882	537
	lower	4050	467
Collins Creek	upper	20000	29600
	mean	16667	17600
	lower	13333	5600
Collins Bay	upper	8333	1614
	mean	6667	1571
	lower	5000	1529
Pow Bay	upper	13333	13040
	mean	10000	12800
	lower	6667	12560
Hidden Bay	upper	7333	8160
	mean	6667	8000
	lower	6000	7840
Effluent Creek	upper	3600	3976
	mean	3000	3429
	lower	2400	2882

TABLE 4.6

SEDIMENT ANOVA RESULTS

Dependent Variable	Source of Variation (Classes)			
	Sample Site	% L.O.I.	Fe	Mn
Ra-226 level	N.S.*	N.S.	N.S.	N.S.
U level	$p<0.006$	N.S.	N.S.	N.S.
Ra-226 K_d	N.S.	N.S.	N.S.	N.S.
U K_d	N.S.	N.S.	N.S.	N.S.

* N.S. - not significant

Table 4.7

S-N-K Test Results for Mean Uranium Levels in Sediments by Sample Site

S-N-K Grouping*	Mean Uranium Level (ug/g)	Sample Site
A	180.6	Effluent Creek
A	104.0	Quirke Lake
A	84.2	Pecors Lake
B	27.2	Esten Lake
BC	13.3	Serpent R./Stollery
BC	11.3	Hidden Bay
C	8.7	Pow Bay
C	6.1	Collins Bay
C	5.7	Dunlop Lake
C	5.7	Collins Creek

* different letter combinations = significant differences ($p<0.05$)

Table 4.8

S-N-K Test Results for Mean Uranium Levels
in Sediments by Organic Content (% Loss on Ignition)

S-N-K Grouping*	Mean Uranium Level (ug/g)	% Loss on Ignition
A	8.5	1-7%
B	60.0	8-14%
C	24.7	15-21%
C	21.3	22-28%

*different letters = significant differences ($p<0.05$)

Table 4.9

S-N-K Test Results for Mean Uranium Levels
in Sediments by Iron Content

S-N-K Grouping*	Mean Uranium Level (ug/g)	Iron Content (mg/g)
A	27.2	11-20
A	25.8	21-30
A	22.6	1-10
AB	12.3	31-50
B	8.2	50+

* different letter combinations = significant differences ($p<0.05$)

Table 4.10

S-N-K Test Results for Mean Uranium Levels
in Sediments by Manganese Content

S-N-K Grouping*	Mean Uranium Level (ug/g)	Manganese Content (mg/g)
A	40.2	0.1-0.5
B	13.6	0.5-1
B	11.3	5+
B	7.6	1-4

* different letters = significant differences ($p<0.05$)

Table 4.11

S-N-K Test Results for Mean Ra-226 Levels
in Sediments by Iron Content

S-N-K Grouping*	Mean Ra-226 Level (Bq/g)	Iron Content (mg/g)
A	1.9	21-30
AB	1.5	1-10
AB	1.3	11-20
B	1.1	51+
B	1.1	31-50

* different letter combinations = significant differences ($p<0.05$)

TABLE 4.12

SEDIMENT PRINCIPAL COMPONENTS ANALYSIS: SUMMARY

A. Eigenvalues (Latent Roots) of the Principal Components Extracted from the PCA Correlation Matrix

	Eigenvalue	Difference Between Successive Eigenvalues	Proportion of Variance Represented	Cumulative Proportion of Variance
PRIN1	3.17529	1.24937	0.396912	0.39691
PRIN2	1.92593	0.56720	0.240741	0.63765
PRIN3	1.35873	0.59600	0.169841	0.80749
PRIN4	0.76273	0.33602	0.095341	0.90283
PRIN5	0.42671	0.15939	0.053339	0.95617
PRIN6	0.26732	0.20627	0.033415	0.98959
PRIN7	0.06105	0.03880	0.007631	0.99722
PRIN8	0.02225		0.002781	1.00000

B. Eigenvectors (Loadings) for Attributes in the Original Data Matrix on Each Principal Component

	PRIN1	PRIN2	PRIN3	PRIN4
% L.O.I.	0.402550[a]	-.182656	0.505671[a]	0.166788
% Moisture	0.453157[a]	-.041104	0.450354[a]	0.081183
Fe	0.302800	0.443061[a]	0.066735	0.455638
Mn	0.216573	0.579228[a]	0.013873	-.375958
Ra-226	-.412372[a]	-.087944	0.139529	0.638852[a]
U	0.042809	-.566889[a]	0.234612	-.328872
Ra-226 Kd	-.428016[a]	0.196498	0.458092[a]	0.002390
U Kd	-.372733	0.255793	0.502466[a]	-.316775

	PRIN5	PRIN6	PRIN7	PRIN8
% L.O.I.	-.233325	-.073172	0.674015[a]	-.083530
% Moisture	-.214528	0.250574	-.664011	0.183926
Fe	0.559044[a]	-.341016	-.097836	-.248103
Mn	0.221023	0.508887[a]	0.279238	0.300441
Ra-226	0.157928	0.600075[a]	0.085426	0.047809
U	0.713395[a]	0.053304	-0.016173	0.039622
Ra-226 Kd	0.030416	-.432216	0.004670	0.616911[a]
U Kd	-.057944	0.082817	-.098314	-.650338

Note: a) Attributes with highest loadings; discussed in text.

Table 4.13

INVERTEBRATE ANALYSIS RESULTS: ONTARIO (COMMON NAME IN PARENTHESES)

Location	Genus	Wet Weight of Total Sample (g)	Ra-226 Bq/g wet wt.	U ug/g wet wt.
Dunlop Lake	Hexagenia (mayfly)	0.81	0.03	<0.3
		0.93	<0.005	<0.3
	Chironomus (midge)	0.28	0.02	0.9
		0.48	<0.01	<0.5
	Procladius Pentaneura Glyptotendipes Endochironomus (midges)	0.30	<0.02	<0.84
	Oligochaetes (worms)	0.72	<0.005	<0.34
Serpent River Immediately Downstream of Dunlop Lake	Hydropsyche (caddisfly)	0.50	<0.01	<0.5
	Rhyacophila (caddisfly)	0.53	<0.01	<0.5
	Cheumatopsyche (caddisfly)	0.96	<0.005	<0.26
		1.0	<0.005	<0.24
		1.2	0.06	0.26
	Paragnetina (stonefly)	2.2	<0.005	<0.003
		2.1	<0.11	<0.12
	Acroneuria (stonefly)	1.6	<0.005	<0.15
	Aeschna (dragonfly)	0.8	0.01	<0.3
	Orconectes (crayfish)	1.2	0.01	<0.2

cont'd

Table 4.13 continued

Location	Genus	Wet Weight of Total Sample (g)	Ra-226 Bq/g wet wt.	U ug/g wet wt.
Esten Lake	Aeschna (dragonfly)	3.5	<0.002	<0.07
	Basiaeschna (dragonfly)	5.2	0.01	<0.05
	Enallagma (damselfly)	0.9	0.01	<0.3
	Leucorrhinia (dragonfly)	2.9	0.01	0.2
		3.7	0.01	0.2
	Chironomus (midge)	2.1	0.05	1.4
		2.2	0.05	1.4
		2.3	0.04	1.4
	Procladius (midge)	1.2	0.05	1.1
	Gyraulus (snail)	3.8	0.01	<0.06
		3.1	0.01	<0.08
	Leech	0.96	<0.005	<0.3
Pecors Lake	Chironomus (midge)	1.9	0.03	6.7
		2.1	0.02	6.2
		1.8	0.03	5.3
	Other Chironomidae	0.33	0.03	8.4
	Agrypnia Platycentropus (caddisflies)	2.9	0.12	17
	Orconectes (crayfish)	8.7	0.08	3.4

cont'd

Table 4.13 continued

Location	Genus	Wet Weight of Total Sample (g)	Ra-226 Bq/g wet wt.	U ug/g wet wt.
Serpent River Immediately Downstream of Pecors Lake	Rhyacophila (caddisfly)	0.44	0.005	<0.56
	Hydropsyche (caddisfly)	9.4	0.02	13
	Cordulegaster (dragonfly)	0.6	0.02	6.8
	Orconectes (crayfish)	5.4	0.05	1.8
		7.9	0.03	1.5
Quirke Lake	Gyraulus (snail)	2.0	0.03	7.0
		2.3	0.03	20
		2.4	0.03	12
	Combined* Physa, Aeschna, Libellula, limnephilid caddisfly Dytiscus, Hydrophilus Helocharea, and Liropeidae	6.3	0.03	12
Serpent River Downstream of Stollery Lake	Simulium (blackfly)	6.2	2.0	45
		10.3	2.0	48
		9.0	1.5	45
		7.8	2.5	49
		7.3	2.5	45

*Combined due to laboratory error

Table 4.14

INVERTEBRATE ANALYSIS RESULTS: SASKATCHEWAN: (COMMON NAME IN PARENTHESES)

Location	Genus	Wet Weight of Total Sample (g)	Ra-226 Bq/g wet wt.	U ug/g wet wt.
Collins Creek	Dipteran pupae	0.47	<0.003	<0.16
	Rhyacophile Hydropsyche Wormaldia (caddisflies)	2.1	0.003	<0.1
	Ophiogomphus (dragonfly)	3.4	0.004	<0.07
		3.3	0.003	0.1
	Ephemerella (mayfly)	1.8	<0.005	<0.14
		1.8	0.003	<0.14
Collins Bay	Oligochaetes (worms)	1.1	<0.005	<0.2
	Procladius/ Orthocladinae (midge)	0.3	<0.02	0.9
	Pontoporeia (water scud)	1.3	<0.004	<0.18
		1.3	<0.004	<0.19
		1.5	<0.003	<0.17
		1.3	<0.004	<0.19
		1.2	<0.005	<0.21
Pow Bay	Pontoporeia (water scud)	2.3	<0.003	<0.10
		2.1	<0.002	<0.12
		1.9	<0.002	<0.13
		2.4	<0.002	<0.11
		2.2	<0.003	<0.11
	Oligochaetes (worms)	0.02	0.13	<15
Rabbit Creek Mouth	Grammotaulius Nemotaulius (caddisfly)	1.4	0.35	203
		1.3	0.40	179
	Leucorrhinia (dragonfly)	1.3	0.10	75
		1.1	0.12	100
	Phryganea (caddisfly)	2.2	0.19	172
		2.3	0.35	161

Table 4.14 continued

Location	Genus	Wet Weight of Total Sample (g)	Ra-226 Bq/g wet wt.	U ug/g wet wt.
Hidden Bay	Procladius (midge)	0.79	<0.005	<0.30
	Oligochaetes (worms)	0.52	<0.01	<0.50
	Chironomus (midge)	0.67	0.005	1.7
		0.73	0.006	1.2
		0.80	0.006	1.1
Effluent Creek	Phryganea (caddisfly)	2.4	0.007	38
		2.3	0.005	34
		2.3	0.004	33
	Nemotaulius Anabolia Limnephilus Lenarchus (caddisflies)	3.2	0.003	33
		3.1	0.002	33
	Dytiscus larvae (beetle)	1.2	<0.005	0.7

Table 4.15

MEAN RADIONUCLIDE LEVELS AND STANDARD ERRORS FOR REPLICATE INVERTEBRATE SAMPLES

Location	Genus	No. of Replicates	Ra-226 Bq/g wet mean*	Ra-226 Bq/g wet s.e.**	U ug/g wet mean	U ug/g wet s.e.
Dunlop Lake	Hexagenia (mayfly)	2	0.02	0.01	<0.3	0
	Chironomus (midge)	2	0.01	0.01	0.58	0.33
Serpent River at Dunlop lake	Cheumatopsyche (caddisfly)	3	0.02	0.02	0.17	0.05
	Paragnetina (stonefly)	2	0.03	0.03	0.03	0.03
Esten Lake	Leucorrhinia (dragonfly)	2	0.01	0	0.2	0
	Chironomus (midge)	3	0.046	0.003	1.4	0
	Gyraulus (snail)	2	0.01	0	0.04	0.01
Pecors Lake	Chironomus (dragonfly)	3	0.026	0.003	6.1	0.4
Serpent River Downstream of Pecors Lake	Orconectes (crayfish)	2	0.04	0.01	1.7	0.2
Quirke Lake	Gyraulus (snail)	3	0.03	0	13.0	3.8
Serpent River Downstream of Stollery Lake	Simulium (blackfly)	5	2.1	0.2	46.0	0.8
Collins Creek	Ophiogomphus (dragonfly)	2	0.004	0.001	0.07	0.03
	Ephemerella (mayfly)	2	0.003	0.001	0.14	0
Collins Bay	Pontoporeia (water scud)	5	0.002	0	0.09	0.01
Pow Bay	Pontoporeia (water scud)	5	0.001	0	0.06	0

* mean = arithmetic mean
** s.e. = standard error

Table 4.15 continued

Location	Genus	No. of Replicates	Ra-226 Bq/g wet mean*	Ra-226 Bq/g wet s.e.**	U ug/g wet mean	U ug/g wet s.e.
Rabbit Creek Mouth	Grammotaulius Nemotaulius (caddisfly)	2	0.38	0.03	191	12
	Leucorrhinia (dragonfly)	2	0.11	0.01	88	13
	Phryganea (caddisfly)	2	0.27	0.08	167.0	5.5
Hidden Bay	Chironomus (dragonfly)	3	0.006	0	1.3	0.19
Effluent Creek	Phryganea (caddisfly)	3	0.005	0.001	35.0	1.5
	Nemotaulius Anabolia Limnephilus Lenarchus (caddisflies)	2	0.003	0.001	33	0

* mean = arithmetic mean
** s.e. = standard error

Table 4.16

WATER AND SEDIMENT INVERTEBRATE BIOACCUMULATION FACTORS/ONTARIO

Location	Genus		Ra-226 Water**	Ra-226 Sediment***	U Water**	U Sediment***
Dunlop Lake	Hexagenia (mayfly)	upper	10000	3.3	-	0.56
		mean*	6667	2.0	90.9	0.48
		lower	3333	0.91	-	0.42
	Chironomus (midge)	upper	6667	2.2	2758	1.7
		mean	3333	1.0	1758	0.92
		lower	0	0	75.8	0.34
	Procladius Pentaneura Glyptotendipes Endochironomus (midges)	upper	-	1.1	-	0.78
		mean	3333	1	127	0.67
		lower	-	0.91	-	0.58
	Oligochaetes (worms)	upper	-	0.33	-	0.31
		mean	1000	0.30	51.5	0.27
		lower	-	0.27	-	0.24
Serpent River Downstream of Dunlop Lake	Hydropsyche (caddisfly)	upper	-	0.6	-	0.46
		mean	1667	0.5	758	0.40
		lower	-	0.5	-	0.35
	Rhyacophila (caddisfly)	upper	-	0.6	-	0.46
		mean	1667	0.5	758	0.40
		lower	-	0.5	-	0.35
	Cheumatopsyche (caddisfly)	upper	13333	4.4	667	0.41
		mean	6667	2.0	515	0.27
		lower	0	0	364	0.17
	Paragnetina (stonefly)	upper	20000	6.7	182	0.11
		mean	10000	3.0	91	0.05
		lower	0	0	0	0
	Acroneuria (stonefly)	upper	-	0.33	-	0.14
		mean	1000	0.30	227	0.12
		lower	-	0.27	-	0.10
	Aeschna (dragonfly)	upper	-	1.1	-	0.28
		mean	3333	1.0	455	0.24
		lower	-	0.9	-	0.21
	Orconectes (crayfish)	upper	-	1.1	-	0.19
		mean	3333	1.0	303	0.16
		lower	-	0.9	-	0.14

* mean = arithmetic mean
** mL/g (wet weight)
*** g(wet weight)/g (wet weight)

cont'd

Table 4.16 continued

Location	Genus		Ra-226 Water**	Ra-226 Sediment***	U Water**	U Sediment***
Esten Lake		upper	333	0.008	97	0.009
	Aeschna	mean*	250	0.007	67	0.008
	(dragonfly)	lower	200	0.006	51	0.007
		upper	3333	0.008	69	0.006
	Basiaeschna	mean	2500	0.007	48	0.006
	(dragonfly)	lower	2000	0.006	37	0.005
		upper	3333	0.008	417	0.04
	Enallagma	mean	2500	0.007	288	0.03
	(caddisfly)	lower	2000	0.006	221	0.03
		upper	3333	0.008	555	0.05
	Leucorrhinia	mean	2500	0.007	385	0.05
	(dragonfly)	lower	2000	0.006	294	0.04
		upper	16333	0.41	3889	0.36
	Chironomus	mean	11500	0.33	2692	0.33
	(midge)	lower	8600	0.27	2059	0.31
		upper	16667	0.42	3056	0.28
	Procladius	mean	12500	0.36	2115	0.26
	(midge)	lower	10000	0.32	1618	0.21
		upper	3333	0.008	111	0.01
	Gyraulus	mean	2500	0.007	77	0.009
	(snail)	lower	2000	0.006	59	0.007
		upper	1000	0.03	417	0.04
	Leech	mean	750	0.02	288	0.03
		lower	600	0.02	221	0.03
Pecors Lake		upper	260	0.16	1183	0.34
	Chironomus	mean	236	0.13	1017	0.29
	(midge)	lower	217	0.10	875	0.25
		upper	300	0.17	1528	0.45
	"Other	mean	273	0.15	1400	0.40
	Chironomids"	lower	250	0.14	1292	0.37
	Agrypnia	upper	1200	0.67	3091	0.90
	Platycentropus	mean	1091	0.60	2833	0.82
	(caddisflies)	lower	1000	0.55	2615	0.75
		upper	800	0.44	618	0.18
	Orconectes	mean	727	0.40	567	0.16
	(crayfish)	lower	667	0.36	523	0.15

* mean = arithmetic mean
** mL/g (wet weight)
*** g(wet weight)/g (wet weight)

cont'd

Table 4.16 continued

Location	Genus		Ra-226 Water**	Ra-226 Sediment***	U Water**	U Sediment***
Serpent River Downstream of Pecors Lake	Rhyacophila (caddisfly)	upper	50	0.03	51	0.01
		mean*	45	0.03	47	0.01
		lower	42	0.02	43	0.01
	Hydropsyche (caddisfly)	upper	200	0.11	2364	0.69
		mean	182	0.10	2167	0.63
		lower	167	0.09	2000	0.57
	Cordulegaster (dragonfly)	upper	200	0.11	1236	0.36
		mean	182	0.10	1133	0.33
		lower	167	0.09	1046	0.30
	Orconectes (crayfish)	upper	500	0.28	336	0.10
		mean	364	0.20	283	0.08
		lower	250	0.14	238	0.07
Quirke Lake	Gyraulus (snail)	upper	1579	0.27	7059	0.88
		mean	1500	0.21	5200	0.60
		lower	1428	0.18	4962	0.38
	Combined Physa, Aeschna Libellula Limnephilid, Dytiscus, Hydrophilus Helochares and Liropeidae	upper	1579	0.27	5085	0.63
		mean	1500	0.21	4800	0.55
		lower	1482	0.18	4580	0.49
Serpent River Downstream of Stollery Lake	Simulium (blackfly)	upper	13713	2.5	2627	5.2
		mean	12353	2.1	2421	4.5
		lower	11040	1.6	2240	4.0

* mean = arithmetic mean
** mL/g (wet weight)
*** g(wet weight)/g (wet weight)

Table 4.17

WATER AND SEDIMENT INVERTEBRATE BIOACCUMULATION FACTORS/SASKATCHEWAN

Location	Genus		Ra-226		U	
			Water**	Sediment***	Water**	Sediment***
Collins Creek	Dipteran pupae	upper	-	0.04	-	0.06
		mean*	500	0.03	320	0.02
		lower	-	0.03	-	0.01
	Rhyacophila Hydropsyche Wormaldia (caddisflies)	upper	-	0.08	-	0.04
		mean	1000	0.06	200	0.01
		lower	-	0.05	-	0.007
	Ophiogomphus (dragonfly)	upper	1667	0.13	-	0.07
		mean	1333	0.08	280	0.02
		lower	1000	0.05	-	0.005
	Ephemerella (mayfly)	upper	1333	0.10	-	0.10
		mean	1000	0.06	560	0.03
		lower	667	0.03	-	0.02
Collins Bay	Oligochaetes (worms)	upper	-	0.17	-	0.09
		mean	833	0.13	143	0.09
		lower	-	0.10	-	0.09
	Procladius/ Orthocladinae (midge)	upper	-	0.67	-	0.84
		mean	3333	0.50	1286	0. 80
		lower	-	0.40	-	0.79
	Pontoporeia (water scud)	upper	-	0.13	143	0.09
		mean	667	0.10	129	0.08
		lower	-	0.08	114	0.07
Pow Bay	Pontoporeia (water scud)	upper	-	0.05	-	0.02
		mean	333	0.03	240	0.02
		lower	-	0.03	-	0.02
	Oligochaetes (worms)	upper	-	6.5	-	2.4
		mean	43333	4.3	30000	2.3
		lower	-	3.3	-	2.3

* mean = arithmetic mean
** mL/g (wet weight)
*** g(wet weight)/g(wet weight)

Table 4.17 continued

Location	Genus		Ra-226 Water**	Ra-226 Sediment***	U Water**	U Sediment***
Rabbit Creek **** Mouth		upper	5125	20.5	1692	64.6
	Grammotaulius Nemotaulius (caddisfly)	mean	4750	12.7	1592	59.7
		lower	4375	8.8	1492	54.9
		upper	1500	6.0	850	32.2
	Leucorrhinia (dragonfly)	mean	1375	3.7	733	27.5
		lower	1250	2.5	625	23.0
		upper	4375	17.5	1438	54.9
	Phryganea (caddisfly)	mean*	3375	9.0	1392	52.2
		lower	2375	4.8	1346	49.5
Hidden Bay		upper	-	0.14	-	0.08
	Procladius (midge)	mean	833	0.13	600	0.08
		lower	-	0.11	-	0.07
		upper	-	0.28	-	0.13
	Oligochaetes (worms)	mean	1667	0.25	1000	0.13
		lower	-	0.23	-	0.12
		upper	-	0.33	-	0.76
	Chironomus (midge)	mean	2000	0.30	5200	0.65
		lower	-	0.15	-	0.54
Effluent Creek		upper	600	0.25	-	0.74
	Phryganea (caddisfly)	mean	500	0.17	2059	0.60
		lower	400	0.11	-	0.50
	Nemotaulius Anabolia Limnephilus Lenarchus (caddisflies)	upper	400	0.17	-	0.67
		mean	300	0.10	1941	0.57
		lower	200	0.06	-	0.49
		upper	-	0.13	-	0.01
	Dytiscus larvae (beetle)	mean	300	0.10	41	0.01
		lower	-	0.08	-	0.01

* mean = arithmetic mean
** mL/g (wet weight)
*** g(wet weight)/g(wet weight)
**** Sediment-based BFs for Rabbit Creek may be too high; Sediment Ra-226 and U levels not available for actual sample site

TABLE 4.18

INVERTEBRATE ANOVA RESULTS

DEPENDENT VARIABLE	SOURCE OF VARIATION	
	SAMPLE SITE	FEEDING GROUP
Ra-226 level	$p<0.0001$	N.S.**
U level	$p<0.0001$	$p<0.01$
Ra-226 SBF*	$p<0.0001$	$p<0.0001$
U SBF	$p<0.0001$	$p<0.0001$
Ra-226 WBF*	$p<0.0001$	N.S.
U WBF	N.S.	N.S.

*SBF = sediment - invertebrate bioaccumulation factor
WBF = water - invertebrate bioaccumulation factor

** N.S. = not significant

Table 4.19

S-N-K TEST RESULTS FOR MEAN URANIUM AND RA-226 LEVELS
IN INVERTEBRATES BY SAMPLE SITE

S-N-K Grouping For Uranium	Mean Uranium Level (ug/g)	S-N-K Grouping for Ra-226	Mean Ra-226 Level (Bq/g)	Sample Site
A	148.3	A	0.25	Rabbit Creek
B	46.4	B	2.10	Serpent R./Stollery
C	28.6	C	0.004	Effluent Creek
	17.0	C	0.12	Pecors (littoral)
CD	12.8	C	0.03	Quirke Lake
DE	6.7	C	0.03	Pecors (main site)
EF	4.7	C	0.03	Serpent R./Pecors
EF	3.4	C	0.08	Pecors (trap net)
FG	1.3	C	0.05	Esten (main site)
G	1.21	C	0.02	Pow Bay
G	0.88	C	0.005	Hidden Bay
G	0.44	C	0.009	Dunlop (main site)
G	0.15	C	0.02	Dunlop (TD #1)
G	0.15	C	0.003	Collins Bay
G	0.13	C	0.02	Serpent R./Dunlop
G	0.10	C	0.008	Esten (littoral)
G	0.06	C	0.003	Collins Creek

* different letter combinations = significant differences ($p<0.05$)

Table 4.20

S-N-K TEST RESULTS FOR MEAN SEDIMENT-BASED BF'S FOR URANIUM AND RA-226 BY SAMPLE SITE

S-N-K Grouping For Uranium*	Mean Uranium BF	S-N-K Grouping for Ra-226	Mean Ra-226 BF	Sample Site
A	45.83	A	8.47	Rabbit Creek
B	4.54	B	2.10	Serpent R./Stollery
C	0.82	B	1.75	Pecora (littoral)
C	0.69	B	0.95	Dunlop (main site)
C	0.59	B	0.75	Quirke L.
C	0.49	B	0.60	Effluent Creek
C	0.48	B	0.53	Dunlop (TD #1)
C	0.44	B	0.40	Hidden Bay
C	0.40	B	0.34	Pow Bay
C	0.32	B	0.25	Pecora (main site)
C	0.27	B	0.21	Serpent R. (Dunlop)
C	0.25	B	0.16	Eaten (main site)
C	0.22	B	0.15	Serpent R./Pecora
C	0.19	B	0.13	Collins Bay
C	0.16	B	0.13	Pecora (trap net)
C	0.05	B	0.06	Eaten (littoral)
C	0.02	B	0.01	Collins Creek

* different letters = significant differences ($p<0.05$)

Table 4.21

S-N-K TEST RESULTS FOR MEAN
WATER-BASED BF'S* FOR RA-226 BY SAMPLE SITE

S-N-K Grouping **	Mean Ra-226 BF	Sample Site
A	13,234	Esten (littoral)
AB	12,353	Serpent R./Stollery
AB	11,875	Esten (main site)
AB	10,000	Dunlop (TD #1)
AB	4,167	Serpent R/Dunlop
AB	3,125	Dunlop (main site)
AB	3,032	Rabbit Creek
AB	1,633	Hidden Bay
AB	1,548	Collins Bay
AB	1,500	Quirke L.
AB	1,091	Pecors (littoral)
AB	1,055	Pow Bay
AB	944	Collins Creek
AB	727	Pecors (trap net)
B	433	Effluent Creek
B	250	Pecors (main site)
B	227	Serpent R./Pecors

* All uranium water-based BF's statistically equal among sample sites

** Different letter combinations = significant differences ($p<0.05$)

Table 4.22

S-N-K TEST RESULTS FOR MEAN URANIUM AND RA-226 LEVELS
IN INVERTEBRATES BY FEEDING GROUP

S-N-K Grouping For Uranium	Mean Uranium Level (ug/g)	S-N-K Grouping for Ra-226	Mean Ra-226 Level (Bq/g)	Feeding Group
A	22.3	A	0.96	Filter Feeders
B	65.1	B	0.09	Omnivores
C	12.7	B	0.04	Detritivores
C	4.4	B	0.02	Herbivores
C	8.9	B	0.02	Predators

* different letters = significant differences ($p<0.05$).

Table 4.23

S-N-K TEST RESULTS FOR URANIUM AND RA-226
WATER-BASED BF'S BY FEEDING GROUP

S-N-K Grouping For U BF's *	Mean Uranium BF	S-N-K Grouping for Ra-226 BF's*	Mean Ra-226 BF	Feeding Group
A	2013	A	8481	Filter feeders
A	1979	A	6934	Herbivores
A	1958	AB	5075	Predators
A	1639	B	2347	Detritivores
A	553	B	1212	Omnivores

*different letter combinations = significant differences ($p<0.05$)

Table 4.24

S-N-K TEST RESULTS FOR MEAN URANIUM AND RA-226
SEDIMENT-BASED BF'S BY FEEDING GROUP

S-N-K Grouping For Uranium*	Mean Uranium BF	S-N-K Grouping for Ra-226	Mean Ra-226 BF	Feeding Group
A	13.5	A	2.41	Omnivores
B	3.7	B	1.11	Detritivores
BC	2.7	B	1.11	Predators
C	2.3	B	0.55	Filter Feeders
D	0.34	B	0.47	Herbivores

*different letter combinations = significant differences ($p<0.05$)

TABLE 4.25

INVERTEBRATE PRINCIPAL COMPONENTS ANALYSIS: SUMMARY

A. Eigenvalues (Latent Roots) of the Principal Components Extracted From the PCA Correlation Matrix

	Eigenvalue	Difference Between Successive Eigenvalues	Proportion of Variance Represented	Cumulative Proportion of Variance
PRIN1	2.97457	1.64945	0.495962	0.49576
PRIN2	1.32512	0.31393	0.220854	0.71662
PRIN3	1.01119	0.41478	0.168531	0.88515
PRIN4	0.59640	0.51907	0.099401	0.98445
PRIN5	0.07733	0.06196	0.012889	0.99744
PRIN6	0.01538		0.002563	1.00000

B. Eigenvectors (Loadings) for Attributes in the Original Data Matrix on Each Principal Component.

	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5	PRIN6
Ra-226	0.210506	0.648959[a]	0.063737	-.715850[a]	-.041986	0.127565
U	0.567005[a]	-.082879	-.060403	-.052965	0.553698[a]	-.598832[a]
Ra-226 SBF	0.560709[a]	-.068756	0.039897	0.116031	-.789988[a]	-.204308
U SBF	0.557488[a]	-.173835	-.118883	0.118284	0.225201	0.761675[a]
Ra-226 WBF	0.058513	0.731703[a]	-.142120	0.659644	0.073277	-.022120
U WBF	0.074701	0.040593	0.977940[a]	0.148893	0.107190	0.052413

*SBF = sediment-based BF
WBF = water-based BF

Note: a) Attributes with highest loadings; discussed in text.

Table 4.26

IDENTIFICATION OF FISH STOMACH CONTENTS CHOSEN FOR RADIONUCLIDE ANALYSIS

	Hidden Bay			
	Longnose Sucker		Lake Whitefish	
	Average %	Number of Samples out of 4 Containing Food Item	Average %	Number of Samples out of 4 Containing Food Item
Insects				
Ephemeroptera (mayfly)	-	-	-	-
Hemiptera (water bugs)	-	-	-	-
Trichoptera (caddisfly)	1.2	1	-	-
Coleoptera (beetle)	-	-	-	-
Chironomidae (midge)	51.0	4	22.5	2
Heleidae (biting midge)	0.3	1	-	-
Terrestrial Insect Remains	1.2	1	-	-
Molluscs				
Gastropoda (snail)	1.2	1	12.5	1
Pelecypoda (clam)	-	-	2.5	1
Crustaceans				
Amphipoda (water scud)	-	-	-	-
Hydracarina (water mite)	0.3	1	1.2	1
Fish				
Cisco	-	-	-	-
Remains	-	-	50.0	2
Plankton				
Cladocera	-	-	-	-
Algae				
Nostoc	1.2	1	1.2	1
Algal Strands	2.5	1	-	-
Plant Debris	9.8	2	2.5	2
Plant Seeds	5.0	1	1.2	1
Detritus	26.3	4	6.4	2
Unidentifiable	-	-	-	-
Total Number of Fish Analyzed	-	4	-	4

cont'd

Table 4.26 continued

	Collins Bay							
	White Sucker		Longnose Sucker		Lake Whitefish		Northern Pike	
	Average %	Number of Samples out of 2 containing Food Item	Average %	Number of Samples out of 2 Containing Food Item	Average %	Number of Samples out of 3 Containing Food Item	Average %	Number of Samples out of 2 Containing Food Item
Insects								
Ephemeroptera (mayfly)	5.0	1	-	-	-	-	-	-
Hemiptera (water bugs)	0.5	1	-	-	-	-	-	-
Trichoptera (caddisfly)	5.0	1	-	-	-	-	-	-
Coleoptera (beetle)	-	-	-	-	0.3	1	-	-
Chironomidae (midge)	33.0	2	8.0	2	6.0	2	-	-
Heleidae (biting midge)	-	-	-	-	-	-	-	-
Terrestrial Insect Remains	-	-	-	-	-	-	-	-
Molluscs								
Gastropoda (snail)	-	-	2.5	1	28.7	2	-	-
Pelecypoda (clam)	5.0	1	2.5	1	30.0	3	-	-
Crustaceans								
Amphipoda (water scud)	-	-	30.0	1	1.7	1	-	-
Hydracarina (water mite)	-	-	-	-	-	-	-	-
Fish								
Cisco	-	-	-	-	-	-	45.0	1
Remains	-	-	-	-	-	-	50.0	1
Plankton								
Cladocera	-	-	-	-	-	-	-	-
Algae								
Nostoc	-	-	-	-	-	-	-	-
Algal Strands	-	-	-	-	-	-	-	-
Plant Debris	-	-	-	-	-	-	-	-
Plant Seeds	-	-	-	-	1.3	1	-	-
Detritus	51.5	2	57.0	2	32.0	3	5.0	1
Unidentifiable	-	-	-	-	-	-	-	-
Total Number of Fish Analyzed	-	2	-	2	-	3	-	2

cont'd

Table 4.26 continued

	Esten Lake				Quirke Lake			
	Longnose Sucker		Lake Whitefish		White Sucker		Brook Trout	
	Average %	Number of Samples out of 5 Containing Food Item	Average %	Number of Samples out of 5 Containing Food Item	Average %	Number of Samples out of 6 Containing Food Item	Average %	Number of Samples out of 4 Containing Food Item
Insects								
Ephemeroptera (mayfly)	-	-	-	-	-	-	-	-
Hemiptera (water bug)	-	-	-	-	-	-	-	-
Trichoptera (caddisfly)	-	-	-	-	-	-	-	-
Coleoptera (beetle)	-	-	-	-	-	-	-	-
Chironomidae (midge)	36.0	5	46.8	5	20.5	6	-	-
Heleidae (biting midge)	3.0	2	-	-	-	-	-	-
Terrestrial Insect Remains	-	-	-	-	-	-	-	-
Mollusca								
Gastropoda (snail)	-	-	-	-	-	-	-	-
Pelecypoda (clam)	-	-	0.2	1	-	-	-	-
Crustaceans								
Amphipoda (water scud)	-	-	0.2	1	-	-	-	-
Hydracarina (water mite)	-	-	30.0	3	-	-	-	-
Fish								
Cisco	-	-	-	-	-	-	-	-
Remains	-	-	-	-	-	-	-	-
Plankton								
Cladocera	15.0	2	-	-	-	-	-	-
Algae								
Nostoc	-	-	-	-	-	-	-	-
Algal Strands	-	-	-	-	-	-	-	-
Plant Debris	5.0	2	17.0	2	15.0	6	-	-
Plant Seeds	10.0	1	4.0	2	-	-	-	-
Detritus	31.0	5	2.0	1	39.5	6	10.0	2
Unidentifiable	-	-	-	-	25.0	6	10.0	2
Total Number of Fish Analyzed	-	5	-	5	-	6*	-	4**

* two samples; each sample consisting of 3 stomachs
** two samples; each sample consisting of 4 stomachs

Table 4.27

RADIONUCLIDE CONTENT OF FISH STOMACH SAMPLES

Location	Species	Sample No.	Sample Wet Weight (g)	Ra-226 (Bq/g wet)	U, total (ug/g wet)
Hidden Bay	Longnose Sucker	LNS-2	4.2410	0.01	61
		LNS-3	3.9170	0.01	48
		LNS-4	14.7114	0.01	19
		LNS-5	20.6115	0.01	54
Hidden Bay	Lake Whitefish	LWF-2	1.4180	<0.004	0.23
		LWF-4	0.5772	<0.01	0.84
		LWF-5	1.2481	0.02	0.27
		LWF-6	2.5206	0.01	1.7
Collins Bay	White Sucker	CWS-1	5.6135	0.005	0.21
		CWS-3	4.9478	0.007	0.23
Collins Bay	Longnose Sucker	LNS-5	4.7909	0.007	0.43
		LNS-10	1.2485	0.005	0.35
Collins Bay	Lake Whitefish	LWF-1	3.0669	0.005	0.35
		LWF-3	1.7407	0.01	1.3
		LWF-5	2.6979	0.005	1.9
Collins Bay	Northern Pike	NP-2	8.4304	<0.01	<0.06
		NP-8	4.6071	<0.001	0.06
Esten Lake	Longnose Sucker	LNS-1	1.6529	0.04	0.67
		LNS-2	0.3812	1.3	2.4
		LNS-3	6.9341	0.18	0.29
		LNS-7	5.7223	0.20	0.37
		LNS-9	0.7882	0.07	0.97
Esten Lake	Lake Whitefish	LWF-1	2.2816	0.01	1.6
		LWF-2	0.9006	0.01	1.5
		LWF-3	1.1664	0.005	0.23
		LWF-5	0.5616	0.02	1.2
		LWF-10	0.4288	<0.01	<0.06
Quirke Lake	White Sucker	composite of 3 stomachs	4.9443	0.13	20
		composite of 3 stomachs	3.8004	0.10	21
Quirke Lake	Brook Trout	composite of 2 stomachs	1.3044	0.02	2.6
		composite of 2 stomachs	1.5625	<0.004	0.40

5.0 DISCUSSION

5.1 Sediments

5.1.1 Uranium and Radium-226 Levels

Uranium and radium-226 levels were found to be consistently elevated above background levels in sediments at sampling sites downstream of tailings area discharges. This observation suggests that sorption on suspended matter and removal from the water column by sedimentation is a major mechanism of transfer of radionuclides to the sediment. The settling of particles has often been found to be the most important pathway for trace metals reaching sediments (Warren 1981).

Uranium was found to be the only parameter which varied significantly with sampling site. The organic content of sediments (as measured by loss on ignition) was related to U levels in sediments in this study (highest U in sediments with moderate amounts of organic material). Organic matter, particularly in the form of humic acids can be a strong sorber of trace elements (Forstner and Wittmann 1979).

Some humic and fulvic acids are natural chelators and may increase solubility and availability of radionuclides in sediments (Whicker and Schultz 1982). This latter phenomenon may explain the lower U levels in sediments with high organic contents in this study. Organic matter can be the most important factor controlling adsorption/desorption processes in sediments (Dyck 1974, Titayeva et al 1978). However, interactions between organic matter, pH, redox potential, sediment texture, and hydrous oxides of iron and manganese can create a very complex and dynamic system that varies with time

(Tada and Suzuki 1982, Whicker and Schultz 1982, Forstner and Wittmann 1979).

The relationship between U and Ra-226 levels and iron and manganese content in sediments in this study was the opposite of what was expected. Manganese oxides are among the strongest sorbers of trace elements, while iron oxides, though less powerful sorbers, are usually present in much greater amounts (Forstner and Wittmann 1979). In addition, iron and manganese oxides reduce U to the tetravalent form which in turn has a high affinity for organic matter (Sheppard 1980). Therefore, one would expect higher radionuclide levels in sediments with higher iron and manganese levels. This was not the case in this study. The lack of a good representative range of sediment types across all levels of radionuclides encountered may account for this apparent anomaly.

The texture or grain size of sediments is known to affect trace element levels (Forstner and Wittmann 1979). In general, the finer the sediments, the more surface area is available, and the greater are trace element concentrations. There was no direct measurement of grain size in this study. Percent moisture was used as an indirect measure; ie. the coarser the sediments, the lower the moisture content. A definite relationship between % moisture and U or Ra-226 levels was not found. The lack of a range of radionuclide levels for different moisture categories may have contributed to the absence of a significant relationship.

5.1.2 Uranium and Radium-226 K_d's

The K_d's in this study were uniformly high. This finding suggests that by far the greatest proportion of radionuclides in the systems were in the sediments. The sediments, therefore, can

be either an important sink or an important source of radionuclides to biota, depending upon the form and availability of the radionuclides.

There were no significant relationships between any of the parameters tested in this study and K_d's. This was unexpected, given the significant effects on U and Ra-226 levels.

The literature shows that K_d is a function of many physical and chemical variables of the solid, liquid and the radionuclide (Whicker and Schultz 1982). Radionuclides differ with respect to their propensity to be adsorbed onto sediment particles. For example, one mechanism of adsorption is cation exchange; cations replace each other on surfaces and the "replacement power" varies with the cation. Radium has very high replacing power (RP); U's RP is not as high (Whicker and Schultz 1982). Therefore it would be expected that K_d's for Ra-226 would be consistently greater than the K_d's for U in the same environment. The K_d's reported in Table 4.5 for Ra-226 and U do not consistently support this hypothesis.

The use of K_d's assumes "first-order kinetics" with respect to movement of radionuclides to sediments. That is, systems behave as a linear function. However, some systems behave as a power function (Whicker and Schultz 1982). This implies that those parameters governing the rate of exchange between water and sediment are not constant, but rather are changing with time. It may also suggest a complex surface, absorption, and possibly several mechanisms of uptake and retention.

Because of the complex interactions that govern water - sediment exchange of the radionuclides, K_d values, while assumed to be constant for a given system under specified conditions, vary over many orders of magnitude for different situations. It is,

therefore, not surprising that no consistent trends in K_d's were observed in this study.

5.2 Invertebrates

5.2.1 Uranium and Radium-226 Levels

The proximity of the sampling sites to uranium tailings areas was significantly related to the U and Ra-226 levels observed in the invertebrates. Since both water and sediment Ra-226 and U levels were also elevated in the receiving environment downstream of tailings areas this observation was not unexpected.

Food predilection and availability are important factors governing radionuclide intake by organisms. The 5 "feeding groups" of invertebrates in this study are exposed to foods that differ in their degree of accumulation of radionuclides. For example, herbivores eating short-lived leaves of aquatic plants may be exposed to smaller amounts of radionuclides than detritivores eating litter that has been accumulating over a long period of time (Klement 1982).

Uranium levels in invertebrates from sites downstream of effluent discharges were more elevated above background than Ra-226 levels. There were some significant differences however, in both U and Ra-226 levels among the invertebrate feeding groups. Filter-feeders (mainly blackfly larvae, and caddisflies in the family Hydropsychidae) had significantly higher U and Ra-226 levels. Omnivores (mainly caddisflies in the families Limnephilidae and Phryganeidae) had higher U levels. Filter feeders capture and feed on suspended particles in the water. These particles can be sediment particles, live organisms or detrital plant and animal material. Omnivores are opportunists, feeding on plant, animal or detrital material. Given the strong

tendency for radionuclides to adsorb onto sediment or detrital material, higher levels in invertebrates ingesting these materials is to be expected.

Detritivores, species which ingest detritus (and sediment along with it), often accumulate the highest concentrations of trace elements in aquatic systems. For example, burrowing mayflies and some Chironomidae (midges) had the highest heavy metal levels among 40 aquatic invertebrate taxa tested (Smock 1983). Detritivores in this study did not have significantly higher radionuclide levels. This may have been due to lack of detritivore samples spanning a wide range of radionuclide concentrations and sample sites. The detritivores in this study (mainly midges, worms and water scuds) were more often collected in control areas or areas that were some distance from effluent discharges.

5.2.2 Uranium and Radium-226 Bioaccumulation Factors for Benthos

Sediment-based BF's were much lower than water-based BF's in this study. Low uptake of radionuclides from sediments may be due to their relative "unavailability". That is, they may be present in tightly sorbed, or insoluble forms. This conclusion conforms with findings reported in the literature. Tessier et al (1984) found that accumulation of trace metals by a freshwater snail was best related, not to total metal concentrations in the adjacent sediment, but rather to one or more of the relatively easily extracted fractions. Accumulation was also influenced by the protective or competitive effect of other sediment constituents, notably iron oxyhydroxides and, to a lesser degree, organic matter. From this and other examples, it is clear that uptake, retention, and hence, bioaccumulation of a radionuclide are governed to a large extent by chemical properties of the radionuclide (Klement 1982).

Interactions between the chemistry of radionuclides and the chemistry of the environmental medium (water or sediment) also govern bioaccumulation. For example, total dissolved solids (TDS) content can have a major influence on uptake. In general, the higher the TDS, the lower the uptake of radionuclides due to adsorption or formation of insoluble compounds (Patzer 1976). In addition, higher TDS means higher concentrations of essential nutrients and therefore lower uptake of radionuclides that are chemically analogous to nutrients (Klement 1982). For example, Ra-226 is chemically analogous to calcium. The higher the calcium levels in water, the lower the uptake of Ra-226. In this study, water-based Ra-226 BF's were often higher in invertebrates from control sites or sites farther away from effluent sources (Tables 4.15 and 4.16). The TDS at these sites was lower.

Alkalinity can also affect BF's through its effect on radionuclide solubility. Carbonate and bicarbonate complexes of U are very soluble (RECS 1978). Therefore, at higher alkalinities U is more soluble and more available for uptake. In this study, water-based U BF's were often higher in invertebrates from sites near effluent sources (Tables 4.15 and 4.16). The alkalinity at these sites was higher.

Biological factors can also strongly affect bioccumulation. Two of the most important biological factors are food habits and habitat selection. Food habits were definitely correlated with BF's in this study. Discrimination among feeding groups was strongest for water-based Ra-226 BF's and sediment-based U BF's. Benthic feeding groups differed with respect to Ra-226 uptake from water as follows: filter feeders/herbivores > predators > detritivores/omnivores. Feeding groups differed with respect to U uptake from sediment as follows: omnivores > detritivores > predators > filter feeders > herbivores.

The above separation of benthic feeding groups implies three things: (1) Ra-226 uptake may be largely via intake of dissolved Ra-226; (2) U uptake may be largely via ingestion of solid material; and (3) it cannot be assumed that radionuclide levels always decrease with successive steps in a food chain. The first two tentative conclusions are based upon the greater statistical discrimination of feeding groups via water BF's for Ra-226 and sediment BF's for U. The last point illustrates that the relative amounts of ingestion of water (for radionuclides such as Ra-226) or sediment (for radionuclides such as U) may be more important determinants of BF's than position in food chains per se. For example, herbivores crawling along aquatic plant leaves eating the algal coating on the leaves or the leaves themselves may be ingesting less U than a predator crawling amongst detritus and ingesting detritus accidentally along with its prey.

The importance of habitat is illustrated by the last example. Burrowing species, regardless of whether they are herbivores, detritivores or carnivores, will be in greater contact with sediments which, in turn, have higher overall radionuclide levels (Klement 1982, Smock 1983). Therefore, these species may accumulate more radionuclides either through ingestion or adsorption onto their exoskeleton. Habitat was not significantly related to BF's in this study; however, there was an insufficient range of habitats and radionuclide levels to allow meaningful comparisons.

5.3 Comparison of K_d's and BF's with Those Obtained in Other Studies

There were very few data with which to compare the results of this study. Both K_d's and BF's in this study are of the same magnitude as those previously reported (Tables 5.1 and 5.2).

However, there are no consistent trends in either K_d's or BF's.

5.4 Fish Stomach Content Radionuclide Levels

The limited fish stomach contents data obtained in this study indicate that radionuclide levels are frequently higher than levels in invertebrate samples. This reflects the mixture of materials in fish stomachs which often includes non-invertebrate material such as algae, higher plant debris and fish. The mixture of materials in fish stomachs is also constantly changing with season and availability of food items and varies with species (Appendix II). Also, favourite foods of fish often include organisms that are very small and difficult to collect in large quantities for direct radionuclide analysis, e.g. water mites, Daphnia or copepods (Appendix II). Therefore, the acquisition of useful data for estimation of radionuclide transfer to whole fish or fish flesh via food consumption depends upon the analysis of fish stomach contents and fish flesh samples on several occasions. To provide data for use in calculating human dose all major species eaten by man should be sampled. Direct invertebrate data may be applicable for more general models and are very useful in terms of understanding radionuclide movement in ecosystems.

5.5 Assumptions and Provisos for the Use of K_d's and BF's

Some assumptions and provisos to remember when using K_d's and BF's are listed below. These are based on the results of this study and on the literature.

(1) K_d's and BF's are calculated assuming that an equilibrium or steady-state exists between input and output to the water/sediment, water/invertebrate or sediment/invertebrate compartments.

(2) The use of K_d's and BF's assumes a linear relationship between concentrations in one "compartment" (eg. sediment) and another (eg. invertebrate). That is, the transfer between compartments is assumed to follow "first-order kinetics".

(3) Site and circumstance-specific data are required for accurate, credible prediction of transfer between environmental compartments at each site (eg. need specific information on sediment organic content, invertebrate feeding groups, etc.)

(4) It is not prudent to assume that radionuclides will consistently increase or decrease along benthic food chains.

(5) In using the K_d's and BF's reported in this study it should be recognized that the values are subject to the following limitations: most water quality parameters were determined on single samples; there were few or no replicates for many of the invertebrate samples; and there was only a limited number of benthic habitats, sediment types and feeding groups sampled across a range of radionuclide levels.

TABLE 5.1

SUMMARY OF REPORTED DISTRIBUTION COEFFICIENTS (K_d)

FOR Ra-226 and U (mL/g (wet))

Source	Location	Date Sampled	Radium-226 Range	Uranium Range
Canada Wide Mines 1981	N. Sask.	1979	1800-6200	
Swanson 1984	N. Sask.	1979 - 1982	205-15833	0.3-3200
Markose et al 1978	India	-	2,900-11900	
Gulf Minerals Canada Ltd. 1980	N. Sask.	1979	171 (dry)	
NUTP	N. Ontario	1984	1500-53333	467-13000
1985*	N. Sask.	1984	2400-20000	1529-29600

* this study

TABLE 5.2

RANGE OF BFs FOR SOME INVERTEBRATE GROUPS

GROUP	Ra-226 Range		U Range		Location	Reference
	Water-Based†	Sediment-Based††	Water-Based†	Sediment-Based††		
Chironomids	7000-9558	0.12-1.3	0.88-17	0.10-0.22	N. Saskatchewan	Swanson 1982, 1984
	833-3333	0.13-0.67	600-5200	0.07-0.84	N. Saskatchewan	NUTP 1985*
	217-16,333	0.14-2.2	76-3889	0.21-1.7	N. Ontario	NUTP 1985
Blackflies	153-455	0.74-0.90	0.60-570	0.22-0.27	N. Saskatchewan	Swanson 1982, 1984
	11,040-13,713	1.6-2.5	2240-2627	4.0-5.2	N. Ontario	NUTP 1985
Caddisflies	1417-6500	1.1-1.6	6.9-1000	0.27-0.3	N. Saskatchewan	Swanson 1982, 1984
	200-5125	0.05-0.17	200-1941	0.017-0.67	N. Saskatchewan	NUTP 1985
	167-13,333	0.09-4.4	364-3091	0.17-0.90	N. Ontario	NUTP 1985
Dragonflies	41-1000	0.008-2.0	11-870	0.04-0.52	N. Saskatchewan	Swanson 1982, 1984
	1000-1667	0.05-0.13	280-850	0.005-0.07	N. Saskatchewan	NUTP 1985
	167-3333	0.006-1.1	37-1236	0.007-0.36	N. Ontario	NUTP 1985
Molluscs (snails & clams)	250-3900	-	3	-	B.C. Interior	Mahon 1982
	1428-3333	0.006-0.27	59-7059	0.007-0.88	N. Ontario	NUTP 1985
Invertebrates or Benthos	500-1000	-	-	-	-	R.ECS 1978
	1379	-	-	-	N. Saskatchewan	Gulf 1980
	650	-	-	-	Yugoslavia	Blaylock 1982
	1-2	-	-	-	India	Blaylock 1982

*NUTP 1985 - this study

† $\frac{\text{Bq/g wet weight of invertebrate}}{\text{Bq/mL (total) in water}}$

†† $\frac{\text{Bq/g wet weight of invertebrate}}{\text{Bq/g wet weight of sediment}}$

6.0 CONCLUSIONS

1. Uranium in sediments was shown to vary significantly among sampling sites while radium-226 was found to be less dependent on site location. Both uranium and radium-226 levels in sediments were related to iron, manganese and organic content.

2. Uranium and radium-226 K_d's were not significantly related to any of the parameters tested in this study.

3. Uranium and radium-226 levels in benthic invertebrates were related to sample site and invertebrate feeding group.

4. Sediment-based BF's were very low compared to water-based BF's.

5. Uranium and radium-226 BF's were related to sample site. This relationship may be partially due to the effects of total dissolved solids and alkalinity.

6. Sediment-based uranium BF's were significantly different among benthic invertebrate feeding groups (omnivores > detritivores > predators > filter feeders > herbivores).

7. Water-based radium-226 BF's were significantly different among benthic invertebrate feeding groups (filter feeders/ herbivores > predators > detritivores/omnivores).

8. For the purposes of understanding radionuclide movement in ecosystems, K_d's and invertebrate BF's are useful.

9. Radionuclide levels do not always decrease or always increase with successive steps in a benthic food chain.

10. For the purposes of estimating radionuclide bioaccumulation in fish, measurement of the radionuclide level in fish stomach contents may yield more accurate data than direct measurement in invertebrates.

11. Use of K_d's and BF's to describe benthic communities demands site- and circumstance-specific data if accurate credible results are required.

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APPENDIX I
SEDIMENT ANALYSIS RESULTS: SASKATCHEWAN

	Collins Creek			Collins Bay			Pow Bay			Hidden Bay			Effluent Creek		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
%L.O.I.	0.7	1	0.9	18	18	18	7.2	6.8	6.1	17	17	16	19	17	11
% Moisture	22	18	28	83	83	81	66	62	62	82	82	82	74	67	62
Fe (mg/g)	6.7	8.4	6.0	63	70	74	18	17	13	48	53	47	15	11	4.3
Mn (mg/g)	0.17	0.40	0.16	3.7	3.8	4.0	7.5	5.9	4.1	5.2	5.8	5.0	0.09	0.10	0.06
Ra-226 (Bq/g)	0.07	2.0*	0.04	0.09	0.17	0.09	0.02	0.12	0.08	0.12	0.15	0.11	0.09	0.08	0.13
U (ug/g)	1.9	13.6	1.6	6.4	5.9	6.0	9.0	8.5	8.5	11.0	11.7	11.7	187	227	128

SEDIMENT ANALYSIS RESULTS: ONTARIO

	Dunlop Lake			Esten Lake			Pecors Lake			Quirke Lake			Serpent River Downstream of Stollery Lake		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
%L.O.I.	24	23	24	17	16	15	12	13	13	17	25	25	1.2	1.2	1.2
% Moisture	89	89	89	84	84	84	78	74	74	74	81	82	23	25	22
Fe (mg/g)	19	20	16	27	26	24	20	19	22	9.9	8.9	11	21	22	17
Mn (mg/g)	0.75	0.77	0.79	0.70	0.65	0.65	0.24	0.27	0.31	0.23	0.20	0.22	0.30	0.29	0.22
Ra-226 (Bq/g)	0.12	0.14	0.10	1.0	0.7	1.0	0.70	0.90	0.90	0.45	0.90	0.70	1.1	1.0	1.8
U (ug/g)	7.3	4.9	4.9	31.1	22.7	27.7	99.2	82.2	71.4	78.2	118	116	15.7	10.2	14.0

* Anomalous result. Not used to calculate mean.

APPENDIX II

PART A: ELLIOT LAKE AREA FISH STOMACH CONTENTS: SUMMARY
(from fish taken in this study)

Lake	Species	Food Items*
Esten Lake	shiners	blackfly larvae dragonfly nymphs amphipods (water scud) green algae* Heleidae larvae* (biting midge) invertebrate eggs chironomid adults (midge)
	rock bass	Daphnia* (water flea) green algae crayfish (1 fish, 100% of contents)
	darters	Daphnia* (water flea) Diaptomus chironomid larvae (Cryptochironomus) (midge)
	lake trout	rainbow smelt (100%)
	whitefish	Cryptochironomus larvae (midge) Chironomus larvae* (midge) Glyptotendipes larvae*(midge) Sphaerium (clam) Tanypodinae larvae (midge) Chironomus adults* (midge) plant seeds Hydracarina* (possibly Hydrachna) (water mite)
	longnose suckers	chironomid larvae (midge) debris
Dunlop Lake	white suckers	chrinomid larvae* (midge) filamentous algae debris
	walleye	stomachs empty

* most common

cont'd

Appendix II

Lake	Species	Food Items*
Depot Lake	common shiner	Daphnia* (water flea) Heleidae larvae (biting midge) Chironomus adults* (midge) Hydracarina (water mite) Procladius larvae (midge) filamentous algae plant seeds
	rainbow smelt	Daphnia (100%) (water flea)
Quirke Lake	Iowa darters	Diaptomus ostracods* (seed shrimp) beetle chironomid adults (midge) Procladius larvae* (midge) Tanytarsini larvae (midge) Navicula Orthocladinae larvae (midge)
	brook stickleback	Diaptomus ostracods* (seed shrimp) chironomic larvae (midge) terrestrial spider
Pecors Lake	brook stickleback	Daphinia (water flea) Palpomyia (biting midge)
	walleye (small)	chironomid pupae (midge) Daphni (water flea) Palpomyia (biting midge) Tanytarsini larvae (midge) caddisfly larvae* Chironomus larvae* (midge) Pentaneura larvae (midge) chironomid adults* (midge)

* most common

cont'd

APPENDIX II

PART B: WOLLASTON LAKE FISH STOMACH CONTENTS: SUMMARY
(from Sawchyn 1979, Gulf Minerals 1979)

Species	Food Items*
Lake whitefish	small clams and snails * **
	Amphipods (water scud)*
	Chironomids (midge)
	Mayfly nymphs **
	Caddisfly larvae **
	water mites
	fish - stickleback **
lake trout	Fish - ciscoes * **
	Stonefly nymphs
	"Diptera" (flies)
	Terrestrial moths
northern pike	Fish * ** - stickleback
	- trout-perch
	- suckers
	Dragonfly nymphs
arctic grayling	Dragonfly nymphs **
	Mayfly nymphs
	Chironomids (midge)
	Beetles*
walleye	Fish * - sticklebacks
round whitefish	snails*
cisco	Mysis * (opossum shrimp)
	Chironomids
	Terrestrial moths
	Fish - "minnows"
	other zooplankton
burbot	Fish
	Amphipods (water scud)

* most common (Sawchyn 1973)
** most common (Gulf Minerals 1979)

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